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THE TECHNOLOGY QUARTERLY

AND PROCEEDINGS OF THE SOCIETY OF ARTS

VOLUME XVI

BOSTON
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
1903

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY held its first meeting on April 8, 1862. By the act of incorporation, which was accepted at this meeting, the SOCIETY OF ARTS was created as a part of the Institute coördinate with the School of Industrial Science.

The objects of the Society are to awaken and maintain an active interest in the sciences and their practical applications, and to aid generally in their advancement in connection with the arts, agriculture, manufactures, and commerce. Regular meetings are held semi-monthly from October to May.

The Society discontinued the publication of the *Abstracts of Proceedings* in 1891, and since then has published its proceedings and the principal papers read at its meetings in the *Technology Quarterly*. The present volume contains the proceedings from October, 1902, to May, 1903, inclusive.

The *Quarterly* contains, also, the results of scientific investigations carried on at the Institute, and other papers of interest to its graduates and friends.

Neither the Massachusetts Institute of Technology nor the SOCIETY OF ARTS assumes any responsibility for the opinions or statements in the papers.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Society of Arts.

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Secretary of the Society of Arts.

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Editor of the Technology Quarterly.

ROBERT P. BIGELOW.

BY-LAWS.

Objects of the Society.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement and development in connection with arts, agriculture, manufactures, and commerce.

The Society invites all who have any valuable knowledge of this kind, which they are willing to contribute, to attend its meetings and become members. Persons having valuable inventions or discoveries which they wish to explain will find a suitable occasion in the Society meetings, subject to regulations hereafter provided; and while the Society will never indorse, by vote or diploma or other official recognition, any invention, discovery, theory, or machine, it will give every facility to those who wish to discuss the principles and intentions of their own machines or inventions, and will endeavor at its meetings, or through properly constituted committees, to show how far any communications made to it are likely to prove of real service to the community.

Section I. — Administration.

The immediate management and control of the affairs of the Society of Arts shall be exercised by an Executive Committee, consisting of the President of the Institute and the Secretary of the Society (who shall be members *ex officiis*), and five other members, who shall be elected by the Society of Arts at each annual meeting, to continue in office until other persons have been chosen in their place.

Sect. II. — Duties of the Executive Committee.

The Executive Committee shall elect its chairman, prescribe his duties, and, with the concurrence of the Treasurer of the Institute, fix his compensation when the interests of the Society require that

he should be paid for his services; they may invite any person to preside at any ordinary meeting who is well versed in the subjects to be discussed; they shall appoint the days and times of meeting, when not fixed by the Society, and determine the subjects to be considered at the meetings and the mode of conducting the discussions; they may, with the concurrence of the President of the Institute, make such arrangements for reporting and publishing the proceedings of the Society as they may deem best suited to advance its interests; they may receive moneys in behalf of the Society in aid of its objects, by subscription, donation, or bequest; they shall make a report of their doings to the Society at its annual meeting and at such other times as a report may be called for by a majority of the members present at any meeting; they shall also make a report of their doings to the President of the Institute prior to the annual meeting, and at such other times as the Corporation may require it. Three members shall constitute a quorum for the transaction of business.

Sect. III. — Duties of the President and Secretary.

1. It shall be the duty of the President of the Institute to preside at the annual and the special meetings of the Society, and also at its ordinary meetings when the Executive Committee does not invite a special chairman to preside.

2. It shall be the duty of the Secretary of the Society to give notice of and attend all meetings of the Society and of the Executive Committee; to keep a record of the business and orders of each meeting, and read the same at the next meeting; to keep a list of the members of the Society, and notify them of their election and of their appointment on committees; and generally to devote his best efforts, under the direction of the Executive Committee, to forwarding the business and advancing the interests of the Society. He shall also record the names of the Executive Committee attending each meeting.

Sect. IV. — Funds of the Society.

All the fees and assessments of members, and all moneys received by subscription, donation, or otherwise, in aid of the Society, shall be paid into the treasury of the Corporation, to be held and used for the objects of the Society under the direction of the Executive Commit-

tee, and shall be subject to the order of its Chairman, countersigned by the President of the Corporation.

Sect. V. — Meetings of the Society.

1. The annual meeting of the Society shall be held at the Institute on the second Thursday in May. The ordinary meetings shall be held semi-monthly, or whenever deemed expedient by the Society or by the Executive Committee, excepting in the months of June, July, August, and September.

2. If from any cause the annual meeting shall not have been duly notified or held as above required, the same shall be notified and held at such time as the Executive Committee may direct.

3. A special meeting of the Society may at any time be called by the Secretary on a written request of ten members. Twelve members of the Society shall constitute a quorum for the transaction of business.

Sect. VI. — Members and Their Election.

1. Members of the Society of Arts shall be of three kinds — Associate, Corresponding, and Honorary Members.

2. Candidates for Associate Membership shall be recommended by not less than two members, whose signatures shall be affixed to a written or printed form to that effect. Each nomination shall be referred to the Executive Committee, and when reported favorably upon by them, and read by the Secretary, may be acted upon at the same meeting; the election shall be conducted by ballot, and affirmative votes to the number of three-fourths of the votes cast shall be necessary for an election.

3. Corresponding and Honorary Members may be elected in the same way, on nomination by the Executive Committee.

4. Associate Members shall pay an admission fee of three dollars before being entitled to the privileges of membership, and an annual assessment of three dollars on the first of October of each year, this sum to include subscription to the *Technology Quarterly and Proceedings of the Society of Arts.*

An Associate Member who shall have paid at any one time the sum of fifty dollars, or annual assessments for twenty years, shall become a member for life, and be thereafter exempted from annual assessments.

A member neglecting to pay his annual assessment for six months after being notified that the same is due shall be regarded as having withdrawn his membership, unless otherwise decided by the Executive Committee, which shall be authorized, for cause shown, to remit the assessments for any one year; and which shall moreover be empowered to exempt particular members from assessments whenever their claims and the interests of the Society make it proper to do so.

Sect. VII. — Election of the Executive Committee and of the Secretary.

1. At an ordinary meeting of the Society, preceding the annual meeting, a nominating committee of *five* shall be chosen, whose duty it shall be to nominate candidates for the Executive Committee, to post a list of the names selected in the office of the Secretary, and to furnish printed copies thereof to the members at or before the time of election.

2. At a meeting at which an election is to take place the presiding officer shall appoint a committee to collect and count the votes and report the names and the number of votes for each candidate, whereupon he shall announce the same to the meeting.

3. A majority of the votes cast shall be necessary to an election.

4. In the first organization under these By-Laws, the Executive Committee may be elected at an ordinary or special meeting.

5. Vacancies in the committee occurring during the year may be filled by the Society at an ordinary meeting.

6. The Secretary shall be elected by the Society, on nomination by the Executive Committee, at each annual meeting of the Society, or, in case of a vacancy during the session, at such other time as the Executive Committee may appoint; and he shall be reëligible in the same way at the pleasure of the Society.

7. The compensation of the Secretary shall be fixed from year to year by the Executive Committee with the concurrence of the Treasurer of the Institute.

Sect. VIII. — Committees of Arts.

1. The Members of the Society of Arts may be enrolled in divisions, under the following heads, according to the taste or preference of

the individual; each division to constitute a committee upon the subjects to which it appertains:

(1) On Mineral Materials, Mining, and the Manufacture of Iron, Copper, and other Metals.

(2) On Organic Materials — their culture and preparation.

(3) On Tools and Implements.

(4) On Machinery and Motive Powers.

(5) On Textile Manufactures.

(6) On Manufactures of Wood, Leather, Paper, India Rubber, and Gutta Percha.

(7) On Pottery, Glass, Jewelry, and works in the Precious Metals.

(8) On Chemical Products and Processes.

(9) On Household Economy; including Warming, Illumination, Water-Supply, Drainage, Ventilation, and the Preparation and Preservation of Food.

(10) On Engineering, Architecture, and Ship-building.

(11) On Commerce, Marine Navigation, and Inland Transportation.

(12) On Agriculture and Rural Affairs.

(13) On the Graphic and Fine Arts.

(14) On Ordnance, Firearms, and Military Equipments.

(15) On Physical Apparatus.

2. Any member may belong to more than one of the above-named Committees of Arts, but shall not at the same time be eligible as chairman in more than one.

3. It shall be competent for each Committee of Arts, of ten or more members entitled to vote, to organize; to elect annually in October, or whenever a vacancy shall occur, a chairman; to appoint its own meetings; and to frame its own By-Laws, provided the same do not conflict with the regulations of the Society of Arts.

Sect. IX. — Amendment and Repeal.

1. These By-Laws may be amended or repealed, or other provisions added, by a vote of three-fourths of the members present at any regular meeting of the Society; provided that such changes shall have been recommended and approved in accordance with the By-Laws of the Corporation (see extract from By-Laws of Corporation as

printed below) and presented in writing at a preceding meeting of the Society.

2. These By-Laws shall take effect immediately after their approval by the Corporation and adoption by the Society, and all previous By-Laws are hereby repealed.

As amended December 9, 1897.

EXTRACT FROM THE BY-LAWS OF THE CORPORATION.

SECT. VI. — There shall be a Committee on the Society of Arts consisting of five members, appointed at the annual meeting of the Corporation, to hold office for one year, who shall have the general charge and supervision of the organization and proceedings of the Society, subject to the approval of the Corporation. It shall be their duty, in connection with a committee chosen by the Society, to frame By-Laws for the government of the Society, which shall take effect when adopted by the Society and approved by the Corporation.

Revised February 1, 1894.

LIST OF MEMBERS.

DECEMBER, 1903.

Members are requested to inform the Secretary of any change of address.

THE CORPORATION.

Blake, Francis . . . . . Auburndale, Mass.
Cabot, Samuel . . . . . 70 Kilby Street, Boston, Mass.
* Carson, Howard A. . . . . 20 Beacon Street, Boston, Mass.
Choate, Charles F. . . . . 50 State Street, Boston, Mass.
Draper, Ebin S. . . . . Hopedale, Mass.
** Endicott, William . . . . . 32 Beacon Street, Boston, Mass.
Fairchild, Charles . . . . . 29 Wall Street, New York, N. Y.
Felton, Samuel M., Chicago & Alton R. R., Monadnock Building, Chicago, Ill.
Fish, Frederick P. . . . . 40 Water Street, Boston, Mass.
* Freeman, John R. . . . 812 Banigan Building, Providence, R. I.
Gardner, George A. . . . . 22 Congress Street, Boston, Mass.
Higginson, Francis L. . . . . 50 State Street, Boston, Mass.
Hubbard, Charles W. . . . . 133 Essex Street, Boston, Mass.
Jackson, Charles C. . . . . 24 Congress Street, Boston, Mass.
Lee, Elliot C. . . . . Brookline, Mass.
Lincoln, William H. . . . . 92 State Street, Boston, Mass.
Livermore, Thomas L. . . . . 12 Ashburton Place, Boston, Mass.
Lothrop, Thornton K. . 27 Commonwealth Avenue, Boston, Mass.
Lovering, Charles L. . 53 State Street, Room 843, Boston, Mass.
* Lowell, A. Lawrence . . 171 Marlborough Street, Boston, Mass.
* Lowell, Percival . . . . . 53 State Street, Boston, Mass.
Merriam, Charles . . . . . 50 State Street, Boston, Mass.
Mills, Hiram F. . . . . Broadway, Lowell, Mass.
* Munroe, James P. . . . . 79 Summer Street, Boston, Mass.

Paine, Charles J. . . . . Sears Building, Room 613, Boston, Mass.
Peabody, Robert S. . . 53 State Street, Room 519, Boston, Mass.
Pritchett, Henry S. . Mass. Institute of Technology, Boston, Mass.
Putnam, William L. . . . 50 State Street, Room 59, Boston, Mass.
* Rotch, A. Lawrence . 1124 Board of Trade Building, Boston, Mass.
Sewell, J. B. . . . . Baring Brothers & Co., London, Eng.
Stearns, James P. . . . National Shawmut Bank, Boston, Mass.
Stockton, Howard . . . . . 87 Milk Street, Boston, Mass.
Stone, Charles A. . . . . 93 Federal Street, Boston, Mass.
Thayer, Nathaniel . . . 50 State Street, Room 37, Boston, Mass.
* Thomson, Elihu. . . . . 42 Center Street, West Lynn, Mass.
* Tolman, James P. . . . . 115 Congress Street, Boston, Mass.
Tuttle, Lucius . . . . . 3 North Station, Boston, Mass.
Weld, Charles G. . . . . 70 Kilby Street, Boston, Mass.
Wheeler, Alexander S. . . . 72 Marlborough Street, Boston, Mass.
Whitney, David R. . . . . 85 Devonshire Street, Boston, Mass.
* Wigglesworth, George . . . . 53 State Street, Boston, Mass.
* Williams, Francis H. . . . . 505 Beacon Street, Boston, Mass.

On the part of the Commonwealth.

His Excellency the GOVERNOR.
The Honorable the CHIEF JUSTICE OF THE SUPREME COURT.
The Honorable the SECRETARY OF THE BOARD OF EDUCATION.

---

* Associate Member, Society of Arts.
** Life Member, Society of Arts.

LIFE MEMBERS.

Addicks, J. Edward . . . 903 Harrison Building, Philadelphia, Pa.
Atkinson, Edward . . . . . 31 Milk Street, Boston, Mass.

Beal, James H. . . . . 104 Beacon Street, Boston, Mass.
Bowditch, William I. . . . . 28 State Street, Boston, Mass.
Breed, Francis W. . . . . Lynn, Mass.

Dalton, Charles H. . . . . 20 Beacon Street, Boston, Mass.

Eastman, Ambrose . . . . . 53 State Street, Boston, Mass.
Endicott, William . . . . . 32 Beacon Street, Boston, Mass.

Griffin, Eugene . . . . . 44 Broad Street, New York, N. Y.

Haven, Franklin . . . . 97 Mount Vernon Street, Boston, Mass.
Henck, J. B. . . . . Montecito, Santa Barbara County, Cal.
Hewins, Edmund H. 176 Federal Street, Room 411, Boston, Mass.

Jackson, William . . . . . 50 City Hall, Boston, Mass.

Little, James L. . . . . Goddard Avenue, Brookline, Mass.
Little, John M. . . . . Hotel Pelham, Boston, Mass.
Lowe, N. M. . . . . 88 Court Street, Boston, Mass.

Matthews, Nathan . . . . . 145 Beacon Street, Boston, Mass.
May, F. W. G. . . . . 127 State Street, Boston, Mass.
Moore, Alexander . . . . . 3 School Street, Boston, Mass.

Ordway, John M. . . . . New Orleans, La.

Parker, Walter E. . . . . Agent, Pacific Mills, Lawrence, Mass.
Pickering, E. C. . . Harvard College Observatory, Cambridge, Mass.
Prang, Louis . . . . . 16 Centre Street, Roxbury, Mass.

Sawyer, Edward . . . . . Newton, Mass.
Sawyer, Timothy T. . . . 319 Dartmouth Street, Boston, Mass.
Sayles, Henry . . . . . 42 Beacon Street, Boston, Mass.
Sherwin, Thomas . . . . . Revere Street, Jamaica Plain, Mass.
Shurtleff, A. M. . . . . 9 West Cedar Street, Boston, Mass.
Stevens, B. F. . . . . 91 Pinckney Street, Boston, Mass.
Sullivan, Richard . . . . . 35 Brimmer Street, Boston, Mass.

Tufts, John W. . . . . Camden, Me.

Vose, George L. . . . . Concord, Mass.

Ware, William R. . . . . Milton, Mass.
Watson, William . . . . . 107 Marlborough Street, Boston, Mass.
Whitaker, Channing . . . . . Lowell, Mass.
Wing, Charles H. . . . . Ledger, Mitchell County, N. C.

ASSOCIATE MEMBERS.

Adams, H. B. . . . . 35 Arlington Street, Cambridge, Mass.
Alden, George A. . . . . 170 Summer Street, Boston, Mass.
Alden, John . . . . . Lawrence, Mass.
Allen, C. Frank . . Mass. Institute of Technology, Boston, Mass.
Allen, Samuel E. . . . . 10 Arlington Street, Boston, Mass.
Allen, Walter S. . . . . 34 South 6th Street, New Bedford, Mass.
Allen, William Henry . 291 Commonwealth Avenue, Boston, Mass.
Anderson, Henry S. . . . . .
Andrews, Clement W. . . . . John Crerar Library, Chicago, Ill.
Appleton, Charles B. . . 207 Aspinwall Avenue, Brookline, Mass.
Armstrong, O. S. . . . . Riverside Press, Cambridge, Mass.
Atwood, Frank W. . . . . 98 Commercial Street, Boston, Mass.

Baker, C. F. . . . . 439 Albany Street, Boston, Mass.
Baker, J. B. . . . . 89 Erie Avenue, Newton Highlands, Mass.
Bardwell, F. L. . . Mass. Institute of Technology, Boston, Mass.
Barnes, Herbert H. . . . . Hotel Brunswick, Boston, Mass.
Barstow, George E. . . . . 7 Locust Street, Lynn, Mass.
Bartlett, Dana P. . . Mass. Institute of Technology, Boston, Mass.
Bartlett, Spaulding . . . . . Webster, Mass.
Barton, George H. . Mass. Institute of Technology, Boston, Mass.
Barton, Howard R. . . . . Englewood, N. J.
Bassett, William H. . . . 146 Litchfield Street, Torrington, Conn.
Batcheller, Henry R. . . . . Box 21, Washington, N. H.
Batcheller, Robert . . 55 Commonwealth Avenue, Boston, Mass.
Beasom, C. B. . . . . 248 Tremont Street, Newton, Mass.
Belcher, Donald M. . . Maigneu Filtration Co., 1310 Arch Street, Philadelphia, Pa.
Bemis, A. F. . . . . 89 State Street, Boston, Mass.
Berry, C. W. . . . Mass. Institute of Technology, Boston, Mass.
Bigelow, Charles H. . . . . Salem, Mass.
Bigelow, Otis . . . . . Avenel, Montgomery County, Md.
Bigelow, Robert P. . Mass. Institute of Technology, Boston, Mass.
Binney, Amos . . . . . 526 Exchange Building, Boston, Mass.
Birkholz, Hans . . . . . Holthoff Machine Co., Cudahy, Wis.
Bissell, Hezekiah . . B. & M. R. R., North Station, Boston, Mass.
Bixby, George L. . . . 8 Lockwood Avenue, East Cleveland, Ohio.
Blackmer, Adelaide S. . . . . 31 Devon Street, Roxbury, Mass.

Blodgett, George W. . . . 407 Central Street, Auburndale, Mass.
Blood, Grosvenor T. . . . . 125 Milk Street, Boston, Mass.
Blood, John Balch . . . 22–A Equitable Building, Boston, Mass.
Blood, William H., Jr. . . . . 93 Federal Street, Boston, Mass.
Boyer, Francis H. . . . . Hill Building, Somerville, Mass.
Brackett, Dexter . . . . . 1 Ashburton Place, Boston, Mass.
Bradlee, Arthur T. . . . . Chestnut Hill, Mass.
Braley, Samuel T. . . . . Rutland, Vt.
Breed, Louis B. . . . . 614 Hill Avenue, Wilkinsburg, Pa.
Brophy, William . . . . 17 Egleston Street, Jamaica Plain, Mass.
Bryden, George W. . . N. E. Structural Co., East Everett, Mass.
Burns, Peter S. . . Mass. Institute of Technology, Boston, Mass.
Burton, A. E. . . . Mass. Institute of Technology, Boston, Mass.

Caldwell, Eliot L. . . . . 3 Head Place, Boston, Mass.
Cameron, J. A. . . . . Forge Village, Mass.
Carson, Howard A. . . . . 20 Beacon Street, Boston, Mass.
Carty, J. J. . . . . .
Chandler, F. W. . . Mass. Institute of Technology, Boston, Mass.
Chase, Charles H. . . . . Stoneham, Mass.
Chase, F. D. . . . . Dedham, Mass.
Chittenden, Albert . . . 15 West 29th Street, New York, N. Y.
Clare, James P. . . . . 53 State Street, Boston, Mass.
Clifford, H. E. . . . Mass. Institute of Technology, Boston, Mass.
Coburn, Howard L. . . . . 143 Appleton Street, Boston, Mass.
Codman, J. S. . . . . 31 Milk Street, Boston, Mass.
Coffin, C. A. . . . . General Electric Co., Boston, Mass.
Coffin, F. S. . . . . 433 Walnut Street, Brookline, Mass.
Collins, R. B. . . . 616 Mooney-Bristam Building, Buffalo, N. Y.
Cooke, John W., Electric Storage Battery Co., 60 State Street, Boston, Mass.
Crafts, James M. . . . . 59 Marlborough Street, Boston, Mass.
Craig, J. Holly . . . . . 31 State Street, Boston, Mass.
Crosby, William O. . Mass. Institute of Technology, Boston, Mass.
Crosby, William W. . . . . 8 Court Street, Woburn, Mass.
Cross, C. R. . . . Mass. Institute of Technology, Boston, Mass.
Curtis, Henry P. . . . . The Somerset, Boston, Mass.
Cutter, Louis F. . . . . 33 Chestnut Street, Salem, Mass.

Dana, Gorham . . . . . 41 Allerton Street, Brookline, Mass.

Dates, Henry B. . Clarkson School of Technology, Potsdam, N. Y.
Davis, Frank E. . . Care Washburn & Moen Co., Worcester, Mass.
Davis, Franklin H. . . . Post-Office Box 1606, Philadelphia, Pa.
Day, Ernest W. . . . 225 Mt. Auburn Street, Watertown, Mass.
Day, Nathan B. . . . . 733 Pine Avenue, Montreal, Can.
DeLancey, Darragh . Hollenbeck Avenue, Great Barrington, Mass.
Densmore, Edward D. . . . . 15 Exchange Street, Boston, Mass.
DeWolf, John O. . . . . 1012 Tremont Building, Boston, Mass.
Doolittle, Orrin S. . . . . 445 Oley Street, Reading, Pa.
Draper, William L. . Dodge Mfg. Co., 40 South Forsyth Street, Atlanta, Ga.
Drown, Thomas M. . . . Lehigh University, South Bethlehem, Pa.
Dudley, P. H. . . . . 80 Pine Street, New York, N. Y.
Dunbar, W. O. . . . . 1218 13th Street, Altoona, Pa.
Dunn, Edward H. . . . . 30 South Street, Boston, Mass.
Dwelley, Edwin F. . . . . 25 Baltimore Street, Lynn, Mass.

Ellis, John . . . . . Lonsdale, R. I.
Ely, Sumner B. . . . . 923 Bidwell Street, Allegheny, Pa.
Eustis, W. E. C. . . . . 60 State Street, Boston, Mass.
Eustis, W. Tracy . . . . . 950 Beacon Street, Brookline, Mass.
Evans, Robert D. . . . . 4 Post-Office Square, Boston, Mass.
Ewing, William C. . . . 2380 Washington Street, Boston, Mass.
Eynon, John S. . . . . 20 Kilby Street, Boston, Mass.

Fales, Frank L. . . . Engineers' Department, Commissioners of Water Works, Cincinnati, Ohio.
Fay, H. J. W. . . . . Westborough, Mass.
Farrington, Charles E. . . . . 200 Summer Street, Boston, Mass.
Faunce, Linus . . . . 119 Bellevue Street, West Roxbury, Mass.
Fish, Charles H. . . . Cocheco Manufacturing Co., Dover, N. H.
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AND PROCEEDINGS OF THE SOCIETY OF ARTS

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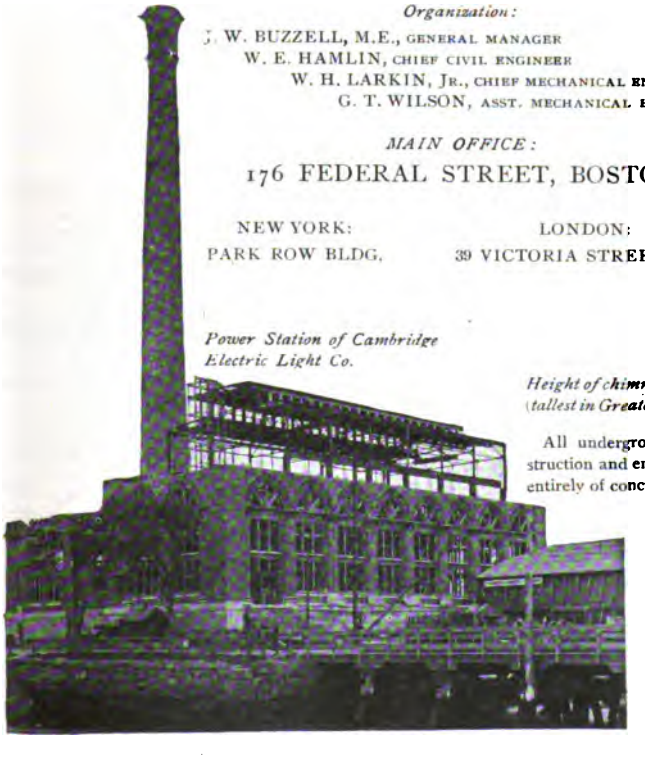

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AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Edited by ROBERT P. BIGELOW, PH D.

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VOL. XVI MARCH, 1903 No. 1

PROCEEDINGS OF THE SOCIETY OF ARTS.

FORTY-FIRST YEAR, 1902–1903.

BOSTON, October 9, 1902.

THE 569th regular meeting of the SOCIETY OF ARTS was held on Thursday evening, October 9th, in the Lowell Building, President Pritchett presiding. Three hundred persons were present. The minutes of the last meeting were read and approved. The resignation of Dr. G. V. Wendell having been received and accepted, the Executive Committee proposed the nomination of Dr. J. F. Norris for the office of Secretary for the year 1902–1903. On the motion of Mr. Munroe, it was voted to instruct the Secretary to cast the ballot of the Society for Dr. Norris.

The address of the evening was then delivered by Professor Louis Duncan, Director of the Department of Electrical Engineering of the Institute, on "Long Distance Electric Railroading." The address will appear in the next number of the TECHNOLOGY QUARTERLY.[1]

[1] TECHNOLOGY QUARTERLY, Vol. XV, No. 4, Dec., 1902, pp. 317–325.

BOSTON, October 23, 1902.

The 570th regular meeting of the SOCIETY OF ARTS was held on Thursday evening, October 23d, in Room 22, Walker Building, Professor Niles in the chair. One hundred and fifty persons were present. The minutes of the previous meeting were read and approved. The following named gentlemen were elected Associate Members of the Society: Mr. Thomas M. Roberts, General Electric Company, Mr. Hezekiah Bissell, Chief Engineer, Boston & Maine Railroad.

Mr. John G. Jack, of the Arnold Arboretum, addressed the Society on "The Identification of Our Woody Plants in Winter."

A vote of thanks was tendered to the speaker, and the meeting adjourned.

BOSTON, November 13, 1902.

The 571st regular meeting of the SOCIETY OF ARTS was held on Thursday evening, November 13, in Room 22, Walker Building, ninety-five persons being present. Professor Clifford presided. After the minutes of the previous meeting were read and approved, the following paper was presented, by title, "Some Notes on Several Types of Mantles for Incandescent Gas Burners," by Mr. William Lincoln Smith. Mr. George H. Bartlett, Principal of the Massachusetts Normal Art School, then addressed the Society on "The Art of Lithography." The technical side of the art was fully discussed and all the materials employed in the process were shown and their use explained. A large number of unusually beautiful lithographs were exhibited. A vote of thanks was tendered the speaker, and the meeting adjourned.

BOSTON, November 28, 1902.

The 572d regular meeting of the SOCIETY OF ARTS was held on Friday evening, November 28th, in Room 22, Walker Building, Professor Peabody in the chair. Three hundred and twenty persons were present. The minutes of the previous meeting were read and approved. Mr. W. Starling Burgess then addressed the Society on "The Designing of Small Racing Yachts." The lecture was illustrated with lantern slides, and a number of models were shown. A vote of thanks was tendered to the speaker, and the meeting adjourned.

BOSTON, December 11, 1902.

The 573d regular meeting of the SOCIETY OF ARTS was held on Thursday evening, December 11th, in Room 22, Walker Building, Professor Talbot in the chair. One hundred and seventy-five persons were present. After the minutes of the previous meeting were read and approved, Professor R. W. Wood of Johns Hopkins University addressed the Society on "A Substance with Remarkable Optical Properties and a Screen Transparent to Ultra-violet Light Only." Professor Wood also gave an account of his diffraction process for color photography. The lecture was illustrated with lantern slides, and a number of experiments were shown. A vote of thanks was tendered the speaker, and the meeting adjourned.

BOSTON, January 8, 1903.

The 574th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, January 8th, one hundred and fifty persons being present. President Pritchett presided. After the minutes of the previous meeting had been read and approved, Mr. S. K. Humphrey was elected to Associate Membership in the Society.

Mr. O. H. Tittmann, Superintendent of the Uuited States Coast and Geodetic Survey, then addressed the Society on "The Coast Survey and Its Work." A vote of thanks was tendered the speaker, and the meeting adjourned.

JAMES F. NORRIS, *Secretary.*

CONTRIBUTIONS FROM THE METALLOGRAPHICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

A STUDY OF THE RELATIONS BETWEEN THE MICRO-STRUCTURE, THE HEAT TREATMENT, AND THE PHYSICAL PROPERTIES OF AXLE STEEL.

BY HENRY FAY, A. W. HIGGINS, AND F. W. COBURN.

THIS investigation was undertaken with the idea of studying the physical properties of some steel such as is used in the manufacture of axles, and the influence of varying heat treatment upon the strength, ductility, and microstructure. General laws have been established by Chernoff[1] and Brinnell[2] in regard to the relations between heat treatment and structure which show an intimate relationship between the structure as shown in the fracture, and the temperature to which the material has been heated. Chernoff clearly observed the methods necessary to prevent coarse crystallization and stated the color temperatures at which the material must be worked in order to obtain the most satisfactory results. Crystalline structure, according to him, was prevented by heating the ingot to a cherry red, at which temperature a fine-grained and strong product was produced; by hammering at a high temperature and continuing the work down to a certain point, which varied with different steels; and by rapid cooling. The point at which these changes are produced is the lower, the higher the carbon of the steel.

Brinnell practically reaches identical conclusions, but he goes further and connects the change of coarse-grained material into fine

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[1] The Structure of Cast Steel Ingots. Proc. Inst. of Mech. Eng., January, 1880; translated from the Russian by W. Anderson. The Manufacture of Steel and the Mode of Working It. Proc. Inst. of Mech. Eng., April, 1880; translated by W. Anderson.

[2] The Changes in the Texture of Steel on Heating and on Cooling. Abstracted in J. Iron and Steel Inst., 1886, No. I, 365.

with the transition of hardening carbon into cement carbon. The transition point he found to vary with the rate of heating or cooling. In the transformation of hardening into cement carbon, rapid cooling from a high temperature lowered this transition point to a lower temperature than it would be if the ingot were allowed to cool slowly from the same temperature. He further points out the relations between the size of the grains and the temperature, the coarsest being obtained at the highest temperature, and the structure remains coarse whether the material is cooled rapidly or slowly from this temperature.

These investigations of Brinnell and Chernoff have been the landmarks from which subsequent investigators have taken their cue. For the most part these results have been verified and confirmed by others. Osmond, Howe, Sauveur, and others have published results in regard to steels containing particular percentages of carbon, and have shown the relation between the heat treatment of these steels and their microstructure.

An apparent exception to the confirmation of these generalizations is the work of Stead[1] on very low carbon steels. The results of his experiments show that in carbonless pure irons or steels the grains increase in size slowly at 500°, and more rapidly at from 650° to 750°, and that it is possible by heating at 700° for a few hours to develop granular masses of exceeding coarseness. At 900° the granules again become small, and heating to 1,200° does not change them. This is an exception to the general laws established by Brinnell, Chernoff, and others, but it must be remembered that the work of Stead was carried on with nearly pure irons, and it is not improbable, as he has shown, that the gases of the furnace have something to do with this peculiar effect.

Various systematic researches have been carried on with steels containing varying amounts of carbon, all of which seemed to confirm the general laws as enunciated by Chernoff and Brinnell. There can hardly be any doubt that there is a very close relationship existing between the properties of any particular steel and the temperature to which it has been heated. In order to establish these relations for a steel such as may be used for axles, we selected a material of the following composition:

[1] J. Iron and Steel Inst., 1898., No. I., 145.

Carbon . . .	0.41	percent.
Manganese . .	0.58	"
Silicon . . .	0.023	"
Sulphur . . .	0.034	"
Phosphorus . .	0.037	"

This material is technically known as "machinery steel," and is used for a great variety of purposes. The specimens used were in the form of bars 18 inches long and $1\frac{1}{2}$ inches in diameter. We wish to express our indebtedness to the Midvale Steel Co. for so kindly furnishing this material.

The heat treatment of these bars was carried on in an electrically heated furnace similar to the one used by Fay and Badlam[1] in their work on low carbon steel. The current was taken from the 110-volt circuit and was used in series with a German silver rheostat. For delicate adjustment a second rheostat was sometimes used.

Temperatures were measured by a Le Chatelier thermo-electric pyrometer. As our furnace was used in connection with two similar furnaces, the lead wires from each passing to the galvanometer were so arranged that the temperature of any one of the three furnaces could be read by closing a switch connecting that furnace with the galvanometer. The junction was held in place by an iron tube passing through the plug which closed the furnace, and was so arranged that when the furnace was closed, the end of the junction rested within a quarter of an inch of the middle part of the bar being heated. The pyrometer was calibrated against boiling water, boiling sulphur, freezing aluminium, and freezing gold.

Before subjecting any of the bars to heat treatment, the critical points of the steel were determined. Two cross sections were cut, one inch in length. Between these clean surfaces the junction was laid, and the two pieces were then bound together by means of an iron wire. The specimen was then heated in an air blast furnace to about 1000° and readings were made on the galvanometer scale during the cooling. It will be seen from Figure 1, in which temperatures are plotted as ordinates and time in seconds as abscissæ, that the Ar_1 point is very well marked at 670°, but the $Ar_{3.2}$ point is not so well developed at 745°.

[1] Tech. Quart., **13**, 295.

The bars were divided into three series, and each series subjected to a similar heat treatment. Bars 1 to 4 inclusive were heated respectively to 700°, 800°, 900°, and 1,000°, held at the respective temperature for four hours, and cooled in the furnace. Numbers 5 to 9 inclusive were heated respectively to 650°, 700°, 800°, 900° and 1,000°, removed from the furnace when the proper temperature was attained and allowed to cool in the air. Bars 10 to 16 inclusive were allowed to cool in the furnace, after being heated respectively to 650°, 700°, 750°, 800°, 900°, 970°, and 1,000°. In

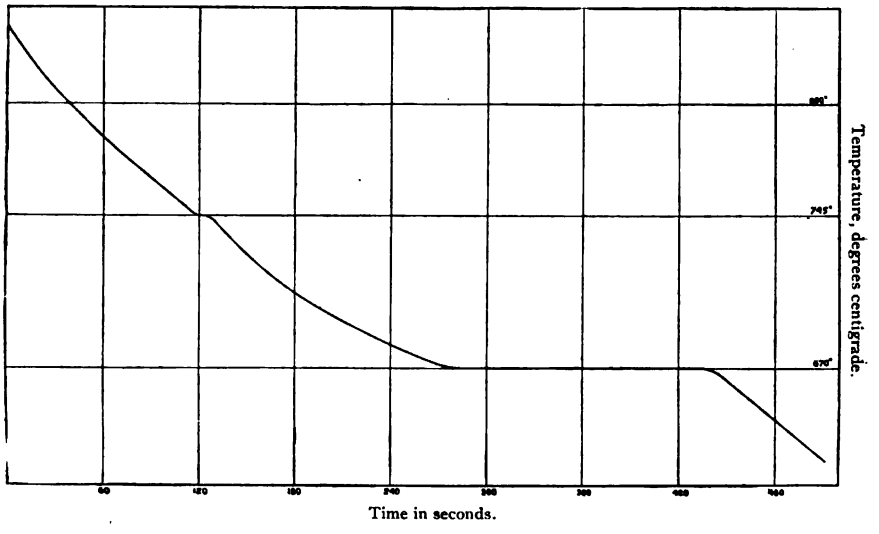


FIG. 1.—CURVE OF COOLING, SHOWING CRITICAL POINTS.

each case the bar was put in the furnace cold and was brought slowly to the required temperature. The temperatures could be regulated almost perfectly by slightly changing the outside resistance. The rate of heating in each case was made as uniform as possible. Where bars were allowed to cool in the furnace, the time of passing from the maximum to room temperature varied from 12 to 18 hours.

For the mechanical tests each specimen was turned down at each end for a distance of 4 inches to $1\frac{3}{8}$ inches in diameter and the central part of 10 inches was turned to a diameter of 1 inch. A 50-ton Olsen machine run by an electric motor furnished the means of breaking the specimens, and could be run at variable speeds.

Slow speed was used and readings of the micrometer were taken at intervals, beginning at 2,000 pounds load.

Specimens for microscopical examination were cut from the shoulder of the broken bar. They were polished to a mirror surface, and then etched by rubbing over a chamois-covered block on which was some rouge and a very dilute ammonium nitrate solution. In some cases this means of etching did not produce enough contrast in the constituents for photographic purposes and this was accomplished by dipping the specimen momentarily in nitric acid and rapidly washing in running water.

Discussion of Results.

The results of the various tests are shown in Table No. I. and by the various curves showing graphically the values for tensile strength, elastic limit, elongation, and reduction of area. The original steel gave a higher tensile strength than any of the other bars. Its microstructure, Figure 4, showed a very uniform distribution of ferrite and pearlite, and gave the suggestion of having been worked to a fairly low temperature. That the original steel showed higher tensile strength than any of the other specimens is perfectly natural. It was probably worked through that interval where crystallization usually takes place on slow cooling, viz., from 1,000° to Ar_1. This work performed on the material in rolling it into round bars prevented crystallization, and it was probably allowed to cool without being worked from Ar_1, which would be the best condition for producing good material. Any heat treatment above Ar_1 would of course destroy this structure, and consequently all results are only relative to those obtained on the original specimen. In Series A, in which the bars were held at varying temperatures for four hours in the furnace, bar No. 1, heated approximately to Ac_1, did not show great change either in physical properties or in microstructure. In bar No. 2, heated to 800° for four hours, there was a considerable falling off in tensile strength and elastic limit, and the microstructure began to show signs of diffusion which became more marked in the specimen heated to 900°. In No. 3 there was still further reduction of the tensile strength, accompanied by reduction in the elongation and increase in the contraction of area. The microstructure, Figure 7, showed a peculiar appearance in which there was very little distinc-

TABLE I. SHOWING TEMPERATURE OF HEATING, METHOD OF COOLING, AND PHYSICAL PROPERTIES.

NUMBER OF SPECIMEN.		TEMPERATURE OF HEATING, DEGREES CENTIGRADE.	MANNER OF COOLING.	TENSILE STRENGTH, LBS. PER SQ. INCH.	ELASTIC LIMIT, LBS. PER SQ. INCH.	ELONGATION IN 8 INCHES.	CONTRACTION IN AREA, PERCENT.	REMARKS ON MICROSTRUCTURE.
1		700	Held 4 hours at maximum. Cooled in Furnace.	93,000	49,600	18.9	42.0	
2	A	800	"	86,100	42,500	18.7	46.3	
3		900	"	80,500	42,700	17.5	52.0	Blurred.
4		1000	"	84,200	41,860	20.5	39.0	Dense masses of pearlite and ferrite.
5		650	Cooled in Air.	94,690	45,230	19.0	38.0	Similar to original.
6		700	"	91,280	44,570	19.9	40.4	Similar to original.
7	B	800	"	91,620	50,970	21.0	46.5	Fine structure.
8		900	"	91,720	48,490	13.0	27.0	Blurred.
9		1000	"	96,510	47,110	17.0	35.5	Large grains of pearlite.
10		650	Cooled in Furnace.	92,050	43,600	18.5	38.5	Similar to original.
11		700	"	91,180	44,390	17.0	39.7	
12		750	"	82,950	36,950	17.0	48.0	
13	C	800	"	86,580	39,500	17.0	46.0	Shows signs of blurred structure.
14		900	"	83,180	40,340	20.1	32.5	Blurred.
15		970	"	86,520	37,290	19.0	32.0	Large area of pearlite.
16		1000	"	78,270	34,570	19.0	38.0	
Original		——	——	95,500	47,000	20.4	37.0	

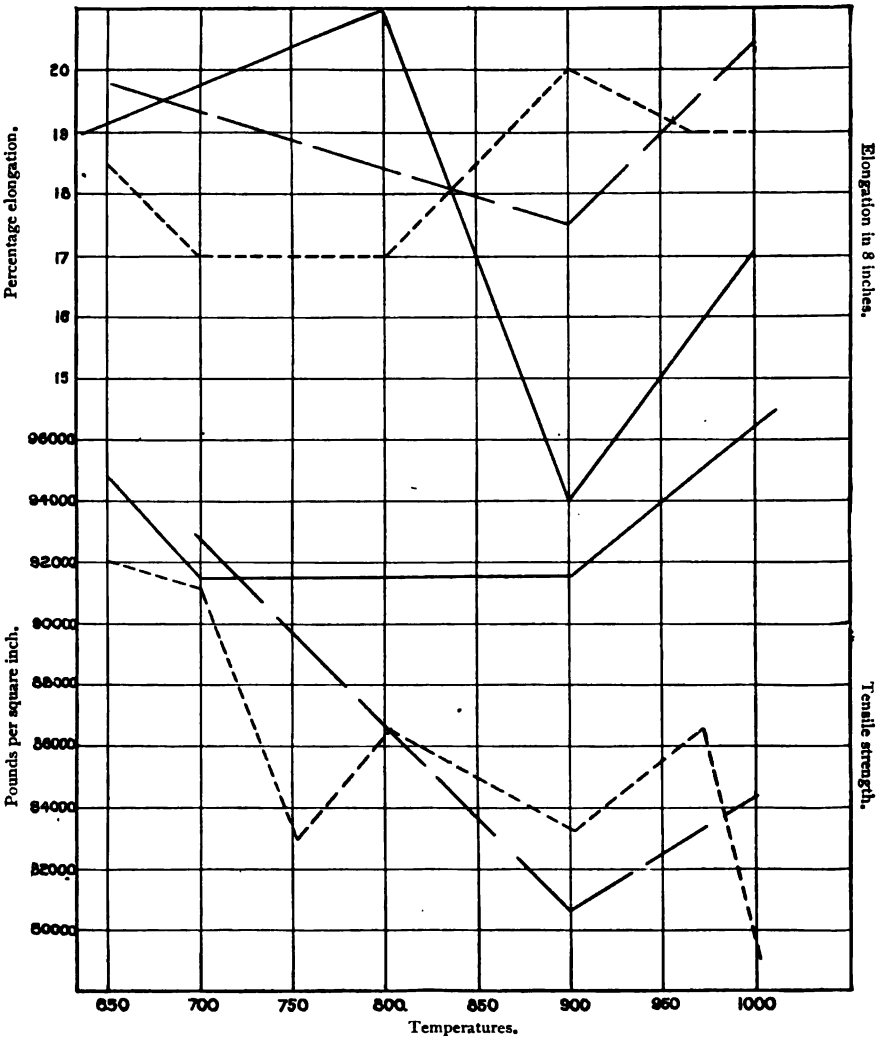


FIG. 2.—GRAPHICAL REPRESENTATION OF RESULTS GIVEN IN TABLE I.

Series A. Long dash line. Bars held at maximum and cooled in furnace.
Series B. Continuous line. Bars cooled in air.
Series C. Dotted line. Bars heated to maximum and cooled in furnace.

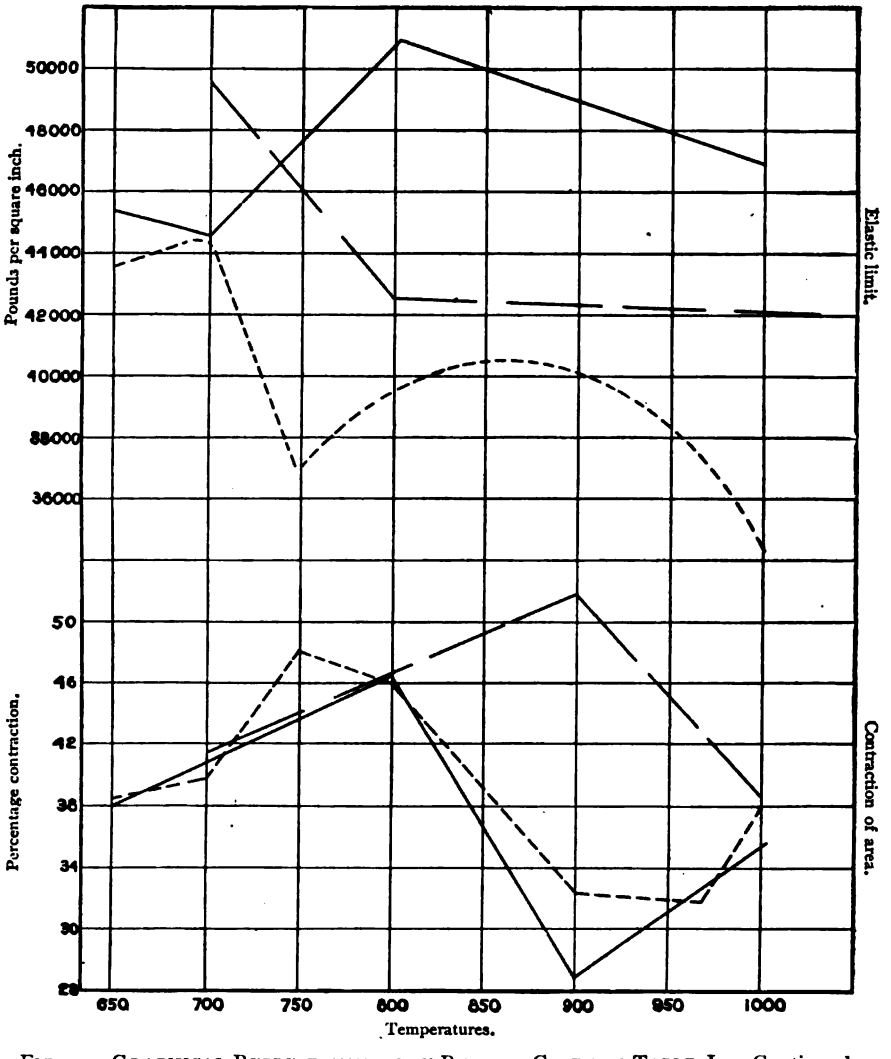


FIG. 3. — GRAPHICAL REPRESENTATION OF RESULTS GIVEN IN TABLE I. — Continued.

Series A. Long dash line.
Series B. Continuous line.
Series C. Dotted line.

tion between the ferrite and pearlite, which would seem to indicate that complete diffusion had taken place at this temperature and that there had not been the subsequent readjustment between the ferrite and pearlite. Specimens 8 and 14, Figures 10 and 13, show this same peculiarity. It does not seem so surprising that readjustment had not taken place in the bar which was allowed to cool in the air, but for those which cooled in the furnace there would seem to be plenty of time for the redistribution of the constituents, ferrite and pearlite. This phenomenon has been observed previously by Göransson[1] and remarked upon by Howe. The material in which it was noticed was in a hyper-eutectic steel containing 1.2 per cent. of carbon.

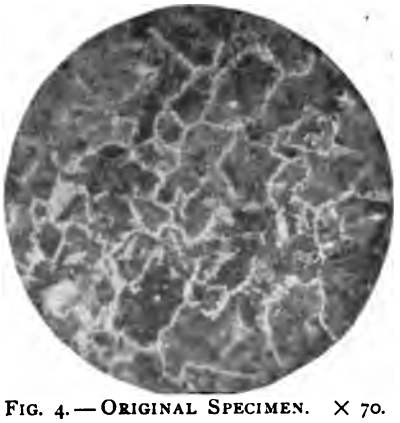


FIG. 4. — ORIGINAL SPECIMEN. × 70.

FIG. 5. — SPECIMEN NO. 1. × 70.
Held 4 hours at 700° and cooled in furnace.

That this is a diffusion process seems to be indicated further by the appearance of specimens 4, 9, 15, and 16, Figures 8, 11, 14, and 15, in which it will be observed that the ferrite and pearlite have begun to segregate in separate masses. In specimen No. 9, this segregation seems to be shown in the process of taking place. The small patches of pearlite seem to be diffusing into the larger areas. This particular phase of the problem will be dealt with in detail when considering that particular specimen.

In bar No. 4 of the series heated four hours, the microstructure shows dense masses of segregated pearlite, this structure being characteristic of all of the pieces heated to 1,000°. The tensile strength

[1] Trans. Am. Inst. Min. Eng., 1902.

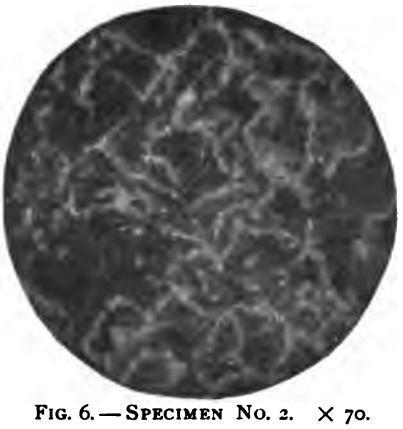


FIG. 6. — SPECIMEN NO. 2. × 70.
Held 4 hours at 800° and cooled in furnace.

FIG. 7. — SPECIMEN NO. 3. × 70.
Held 4 hours at 900° and cooled in furnace.

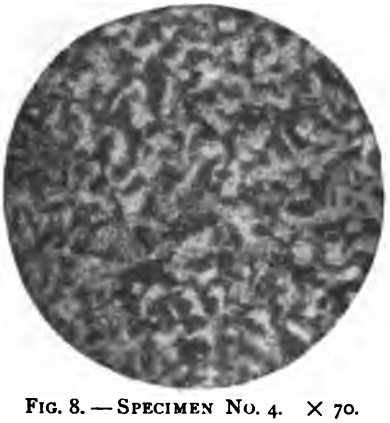


FIG. 8. — SPECIMEN NO. 4. × 70.
Held 4 hours at 1000° and cooled in furnace.

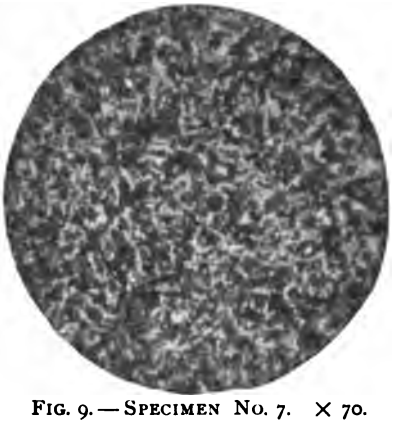


FIG. 9. — SPECIMEN NO. 7. × 70.
Cooled in air from 800°.

FIG. 10. — SPECIMEN NO. 8. × 70.
Cooled in air from 900°.

FIG. 11. — SPECIMEN NO. 9. × 70.
Cooled in air from 1000°.

is higher than in the piece heated to 900°. This is in accord with some other work in which this higher temperature seems to give increased strength. This high strength does not, however, necessarily indicate good material. The other properties must also be taken into consideration. In Series B, in which the bars were heated to definite temperatures and allowed to cool in the air from that temperature, the physical properties are in most respects more desirable than for the bars allowed to cool in the furnace. The tensile strength and elastic limit are uniformly higher, as might be expected. The more rapid cooling in this case gives much less time for crystallization to take place. The maximum elastic limit for the series is obtained at 800°, and it is to be observed that this would be indicated by the microstructure, Figure 9, which is very fine and uniform. Rather surprising is the fact that the strength of bar No. 9, heated to 1,000°, is greater than that of the original material. The microstructure of this bar was in places very coarse, consisting of large masses of pearlite, while in other places it consisted of fine granules of pearlite surrounded by ferrite, Figure 11. It may be pointed out in this connection that a coarse structure is not always associated with low strength, but the piece would, however, suffer badly from any sudden strain or shock.

In connection with the microstructure of bar No. 9, it is interesting to note the fact that a large pearlite area is invariably surrounded by an area of fine-grained pearlite. This would seem to indicate that there was a difference of surface tension between the large and small areas and that the smaller areas were diffusing into the larger, the general tendency being to reduce as far as possible the total surface energy. That this coarse structure is not due to an electrolytic effect of the etching solution, seems to be shown by the fact that different etching agents brought out the same structure, always giving the same arrangement of pearlite and ferrite. Relief-polishing likewise gave the same structure. If this formation of large crystals were an electrolytic effect, it would be difficult to conceive that nitric acid, ammonium nitrate, or alcoholic solution of hydrochloric acid would all produce similar results. Ewing and Rosenhain[1] have demonstrated that there is a difference of solubility of two crystal faces in contact with an eutectic film. Experiment-

[1] Philosophical Transactions, **195**, 279.

ing with lead, they have shown that the orientation of the lead crystal affects its solubility, and that in some cases lead is dissolved from one crystal and deposited upon another, causing the increased growth of the latter. Similar reasoning does not, however, seem to apply to the formation of large areas of pearlite, for here we

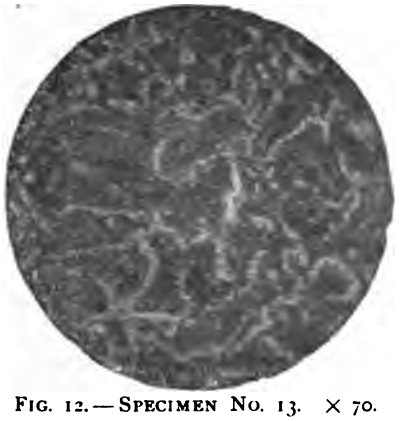


FIG. 12. — SPECIMEN NO. 13. × 70.
Cooled in furnace from 800°.

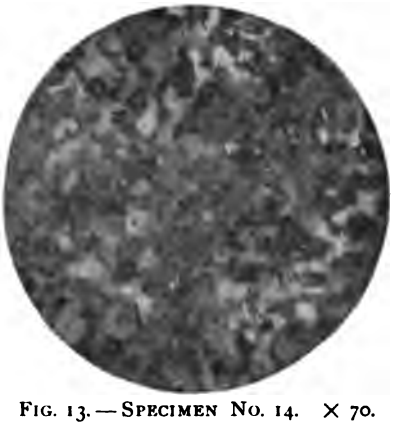


FIG. 13. — SPECIMEN NO. 14. × 70.
Cooled in furnace from 900°.

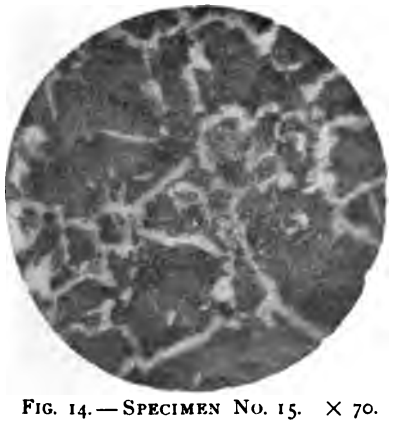


FIG. 14. — SPECIMEN NO. 15. × 70.
Cooled in furnace from 970°.

FIG. 15. — SPECIMEN NO. 16. × 70.
Cooled in furnace from 1000°.

have a complex substance which it would be difficult to conceive that it should be deposited in its characteristic form of alternate layers of iron and iron carbide. The phenomena by which large pearlite areas are produced seems to be similar to the production of large crystalline grains in any precipitate. It is a well known

fact that if we digest precipitated barium sulphate, the crystals will increase in size. This is due to the fact that the smaller crystals are more soluble than the larger ones and they are redeposited on the larger ones, the general tendency being to decrease to a minimum the surface energy. In the case of steel we seem to have a similar phenomenon. The pearlite corresponds to the barium sulphate, and the iron to the solution. At a temperature of 800° to 900°, diffusion is taking place freely, and it may easily be conceived that the smaller areas are diffusing into the larger ones. On heating to the higher temperatures, these areas are developed, and also have their influence upon the coarseness of the fracture.

In Series C, those bars heated to a definite temperature and allowed to cool from that temperature in the furnace, do not show a very marked difference from Series A. The tensile strength is on the average slightly higher, the elastic limit uniformly lower, the contraction of area lower, and the elongation shows on an average about the same values. Compared with Series B, Series C shows uniformly lower tensile strength and elastic limit.

The microstructure of this series is similar to Series A and B in the specimens heated below 800°. The complete blurring of the microstructure seems to have taken place between 800° and 900°. Specimen 14 heated to 900° resembles Specimen 4 heated to 1,000°, and not Specimens 3 and 8 heated to 900°. Complete diffusion evidently took place at about 850°, because the specimen heated to 800° shows some of the blurred effect, and at 900° it seems to have passed partly through this stage. Heated to 970°, Specimen 15 shows large masses of lamellar pearlite surrounded by wide channels of ferrite. Specimen 16 shows dense segregated masses of pearlite. The tensile strength of this piece is abnormally low, and should not show such a variation from Specimen 4 heated to the same temperature for four hours before cooling in the furnace. The rate of heating and cooling has a strong influence on the properties of this material, and it may have been that this specimen was not heated in the same manner as the others, although considerable care was taken to have all conditions as uniform as possible.

The most notable changes occur in this steel in the neighborhood of 900° and not at Ac_1, as would be expected. Whether this is due to the fact that some element is exerting a retarding influence, or whether some unknown influence is acting, remains for

further investigation. Judging from the microstructure and the physical properties of Specimen No. 7, the most satisfactory heat treatment would be to heat to a temperature of 800° and to cool in the air. Of course it must be borne in mind that all of the results obtained are only relative, because the original material received considerable work in the process of manufacture, and this exerted an enormous influence on the properties. The heat treatment as outlined, therefore, refers more particularly to the changes produced in a piece of axle steel which is ready for service.

ON THE PRACTICAL VALUE OF PRESUMPTIVE TESTS FOR BACILLUS COLI IN WATER.[1]

By GEORGE C. WHIPPLE.

Introduction.

The status of the test for *Bacillus coli* in the sanitary examination of drinking water at the present time is one of great uncertainty, and yet there is no subject of more practical importance. The uncertainty is caused in part by the fact that there is no one method generally accepted by which the presence of this organism in water is determined. Each bacteriologist has his own way of isolating it and studying it in pure culture, and the results obtained by these different methods fail to agree. The bacillus itself, in spite of an immense amount of study, is one which cannot be always recognized by the usual methods employed. Its different races and strains so insensibly merge into allied species, and there are such gradations between *Bacillus coli* and *Bacillus typhi* on the one hand and between *Bacillus coli* and several species of common water bacteria on the other hand, that with our present tests it is almost impossible to say what shall or what shall not be called *Bacillus coli*. The type form of *Bacillus coli* is one which can be defined within reasonably narrow limits, but when the organism has been away from its natural habitat for varying periods of time, and has existed under abnormal conditions, its ability to react normally to the usual tests appears to be greatly impaired. Its power to reduce nitrates may be lost, or on the other hand, it may be much increased; its power to produce indol may be lost, or on the other hand, it may be increased; its power to coagulate milk, even, is sometimes reduced, although seldom entirely lost; its power to ferment carbohydrates may be altered so that the amount of gas obtained in a fermentation tube, as well as its ratio of H to CO_2, is quite abnormal. But in spite of all these facts, the bacillus

[1] Paper presented at the meeting of the Laboratory Section of the American Public Health Association held at New Orleans on December 8, 1902.

tested may have been originally a true *Bacillus coli*. It happens, therefore, that a sample of water may contain this bacillus without its being recognized, and it happens also, and perhaps more frequently, that other organisms closely related to this species but different from it, may be recorded as *Bacillus coli*. And this has led to a wide divergence of ideas concerning the distribution of the species in nature, and to the practical significance of positive tests for it in water. So great has been the discord in regard to the results obtained by the usual tests that it has been questioned by some sanitarians as to whether the test as ordinarily made has any practical significance at all. It is my purpose in this article to show that in spite of all these varying results, the test for *Bacillus coli* is one of great usefulness.

In order to determine definitely whether *Bacillus coli* is present or is not present in a sample of water, it is necessary to isolate the germ and study it in pure culture. This involves a long series of operations, and is a time-consuming process. It is seldom that a reliable result can be obtained inside of one week, and preferably the test should extend over a period of ten days, in order to allow for preliminary cultivation.

The following tests may be considered necessary to establish beyond a doubt the identity of the organism:

1. Typical morphological characteristics and motility, as determined from a young broth culture.

2. The non-liquefaction of gelatin as determined by a stab-culture incubated for at least one week, and preferably for a longer period.

3. The fermentation of dextrose broth in a Smith tube. The amount of the gas should be normally between 30% and 70% of the volume of the closed arm, and the percentage which the carbonic acid is of the total amount of gas should be approximately one-third. The closed arm should be turbid and the open bulb should show a strongly acid reaction. It should be noted, however, that both the amount of gas and the percentage of carbonic acid are subject to variation, even with freshly isolated cultures of *Bacillus coli*, so that these quantities must not be given a too strict interpretation.

4. The production of indol in Dunham's Solution, when tested by the "Ring Method" after an incubation of 48 hours at 37° C.

5. The characteristic coagulation of milk, with the production of acid, in 48 hours at 37° C.

6. The reduction of nitrates in 48 hours at 37° C.

7. The non-formation of spores, as determined by the inability of a culture to develop after heating for ten minutes at 80° C.

The most constant of the above tests are the characteristic morphology, non-liquefaction of gelatin, fermentation of carbo-hydrates, and the coagulation of milk. The tests for indol production and nitrate reduction are somewhat more erratic than the others. Before the above tests can be made, it is first necessary to isolate the organism from the water in pure culture. This has been accomplished in a variety of ways. For example: Gelatin plates, agar plates, lactose-litmus-agar plates, phenol-agar plates, or plates of agar which have been otherwise treated in order to inhibit the growth of ordinary water bacteria, are fished, and the cultures put through the regular tests. Or, the sample is added to dextrose broth in a Smith tube, and, if the characteristic fermentation is obtained, is thereafter plated out on agar or some modification of it, as described above, and these plates ultimately fished. Or, the sample of water in quantities which may vary from .01 c.c. to 1 litre, is enriched by the addition of carbolized dextrose broth, or some similar medium, and given a preliminary incubation, after which transfers are made to lactose-litmus plates or to the fermentation tube. In fact, the methods used for isolating *Bacillus coli* in pure culture are varied according to the idiosyncrasies of the operator and the character of the water to be tested. It is not my purpose to describe here these various methods, many of which are of considerable value, and no one of which can be considered as superior to the others for all cases. I wish simply to emphasize the fact that the operation is a tedious and laborious one. In the practical supervision of water supplies it often happens that there is no time for carrying out all of the tests required to obtain an absolutely conclusive result, and that an approximate test which may be quickly made may have greater practical value than the ultimate test. For example: If it only takes 4 days for the water of a reservoir to reach the service taps in a city, and if it requires a week to make a test, the result of a conclusive test could not be learned until several days after the water had been used; while if a presumptive test could be obtained in 48 hours, it might materially affect the management of the water

supply. Hence it is important that the subject of presumptive tests for the presence of *Bacillus coli* should not be overlooked. I have studied this subject with considerable care, and have made practical tests of nearly all methods which have been suggested, including the most recent ones, namely, the neutral red test and the sodium-taurocholate, or bile salt test, as suggested by McConkey; but after all my studies I have found nothing of more practical value than the simple fermentation-tube-test, as first outlined by Smith; and his original test has been modified only by operating upon different volumes of water for each sample. The method of procedure which is used at Mount Prospect Laboratory is as follows:—

Method of Making Presumptive Tests.

Smith tubes of the ordinary form are used, the closed arm being 5 inches long and about $\frac{1}{2}$ inch inside diameter. The following is the formula of the broth used:

Liebig's Beef Extract . . .	10 grams.
Pepton	10 "
Dextrose	10 "
Water	1,000 "

The reaction is made 0%, and the correctness of this reaction is a matter of no little importance.

The medium is made up in batches of 5 litres and kept in flasks until needed to be used in the Smith tubes. Sterilization is made in the autoclave. When quantities of water of .001, .01, .1, 1.0 or 10 c.c. are to be tested, these quantities are added directly to the broth in the Smith tubes, the fractional portions being obtained, of course, by dilution. When larger quantities, such as 100, 500 or 1,000 c.c. are to be tested, they are first enriched by the addition of carbolic dextrose broth of such a strength that after addition to the water the mixture shall contain 1% of dextrose and 0.1% of phenol. After preliminary incubation for a period not exceeding 12 hours, 1 c.c. of the culture is added to a fermentation tube. If the enriched samples are allowed to stand too long, other organisms, such as streptococci, for example, may outgrow *Bacillus coli* so that a negative result may be obtained. The fermentation tubes are incubated at 37° for 48 hours, and are then tested for per cent. of gas, percentage of carbonic acid, reaction of the open bulb, and tur-

bidity of closed arm. The typical reaction which is considered as a positive test for the presence of *Bacillus coli* in the sample tested is as follows: Total gas, between 25 and 70 per cent. of the closed arm; per cent. which the carbonic acid is of the total gas, between 25 and 40; the closed arm, turbid; the open arm, strongly acid to litmus and usually not accompanied by the formation of a scum. If the amount of gas formed is between 10 and 25 per cent., or if it is more than 70 per cent., the test is considered as atypical; or, if the amount of gas is between 25 and 70 per cent., and the per cent. of carbonic acid greater than 40, the test is considered as atypical; or, with the proper gas reactions, but with the open arm alkaline instead of acid, the test is considered as atypical. If no gas forms, or if it is less than 10 per cent., the test is called negative.

It is recognized that this test is not absolute. It has frequently happened that pure cultures isolated from Smith tubes which gave a positive test have failed to yield true cultures of *Bacillus coli* when carried through all the tests by sub-culture; and on the other hand, it has occasionally happened, though rarely, that true cultures of *Bacillus coli* have been obtained from Smith tubes which yield atypical results. But speaking broadly, the typical reactions offer satisfactory presumptive evidence of the presence of this species, or species very closely allied to it.

In a subsequent paper, I hope to give the data to support this assertion, but at this time will offer as corroborative testimony the statement of Mr. Irons, who in his paper on "Some Observations on Methods for the Detection of *Bacillus coli communis* in Water," states: "When the dextrose tube yields approximately 33 per cent. of CO_2, *Bacillus coli communis* is almost invariably present."

Eccentricities of the Test.

When varying quantities of a sample of water are tested in series, it sometimes happens that a positive test is obtained with a small amount, while with larger amounts the results are negative. This anomalous result is due in part to chance, but chiefly to the rapid development, during the preliminary incubation, of bacteria which are not *Bacillus coli*, and which tend to obscure the reaction. It has been observed by Winslow, Gage, and others, that certain streptococci are most commonly the cause of this interference, and

this has been also my own experience. Furthermore, in the waters which have come to me for examination streptococci have been less numerous than *Bacillus coli.* Consequently, when small amounts of water have been tested they have been less likely to cause interference than when large amounts have been examined.

In order to show the frequency with which these interferences occur, the following figures are presented. 140 samples of water were tested, in quantities of 0.1, 1.0, and 10.0 c.c., with the results shown in Table I.:

TABLE I.

SHOWING THE RESULTS OF PRESUMPTIVE TESTS FOR BACILLUS COLI WITH DIFFERENT QUANTITIES OF WATER.

	PER CENT. OF SAMPLES.		
NUMBER OF C.C. OF WATER TESTED.	0.1	1.0	10.0
Positive Tests.	4.0	9.8	24.4
Atypical Tests.	1.3	18.0	30.4
Negative Tests.	94.7	72.2	45.2
Negative Tests in cases where positive tests were obtained with smaller quantities of water.	0.0	2.9	4.3
Negative Tests in cases where atypical tests were obtained with smaller quantities of water.	0.0	0.0	2.8
Positive Tests (Corrected).	4.0	12.7	28.7
Atypical Tests (Corrected).	1.3	18.0	33.2
Negative Tests (Corrected).	94.7	69.3	38.1

It will be seen from this that 2.9% of the samples gave positive tests with 0.1 c.c., but not with 1 c.c., while 4.3% of the samples gave positive tests with 0.1 or 1 c.c., and negative tests with 10 c.c. Again, 169 samples which were tested in quantities of 1, 10, 100 and 500 c.c. gave results shown in Table II.

TABLE II.

SHOWING THE RESULTS OF PRESUMPTIVE TESTS FOR BACILLUS COLI IN DIFFERENT QUANTITIES OF WATER.

	PER CENT. OF SAMPLES.			
NUMBER OF CUBIC CENTIMETERS OF WATER TESTED.	1	10	100	500
Positive Tests.	17.2	26.6	37.9	40.8
Atypical Tests.	25.4	32.6	37.3	37.3
Negative Tests.	57.4	40.8	24.8	21.9
Negative Tests in cases where positive tests were obtained with smaller quantities of water.	0.0	3.0	5.3	4.8
Negative Tests in cases where atypical tests were obtained with smaller quantities of water.	0.0.	5.3	4.7	7.7
Positive Tests (Corrected).	17.2	29.6	43.2	45.6
Atypical Tests (Corrected).	25.4	37.9	42.0	45.0
Negative Tests (Corrected).	57.4	32.5	14.8	9.4

It was found that 0.1% phenol broth possessed but little advantage over uncarbolized broth for preliminary cultivation, and that it made but little difference whether the temperature of the incubator was kept at 37.5° C. or at 42° C., but that it was a decided advantage to use a short period of incubation rather than one which extended over eighteen hours.

The interference of streptococci and other organisms with the presumptive test as conducted in the manner described above is troublesome and difficult to avoid, but, in my experience, it has been found to be serious only in about five per cent. of the samples tested. Whenever a positive test for *Bacillus coli* is obtained with a small quantity of water, it is safer to assume that larger quantities will also give a positive test, than to assume that the positive test in the small quantity was accidental.

PRACTICAL VALUE OF THE PRESUMPTIVE TEST.

As an illustration of the value of this test, I beg to call attention to the diagram shown in Figure 1. This gives the results of chemical and bacteriological examinations of certain surface water

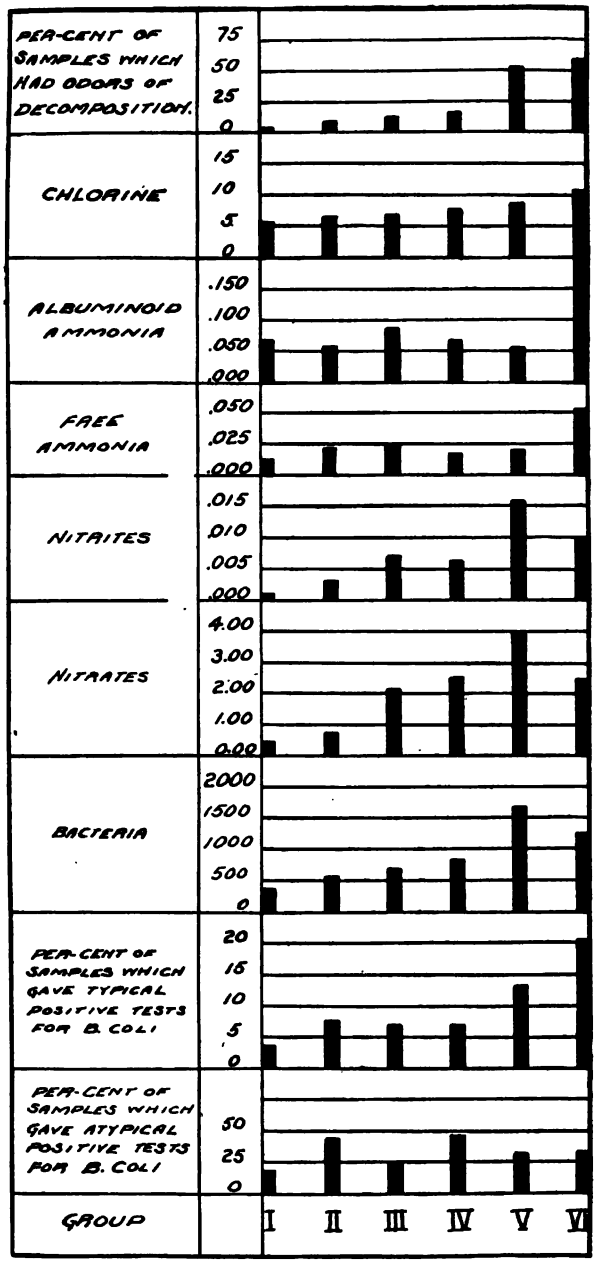


FIG. 1. — DIAGRAM SHOWING THE RELATION OF TYPICAL AND ATYPICAL PRESUMPTIVE TESTS FOR B. COLI TO THE SANITARY ANALYSES OF VARIOUS SURFACE WATERS, ARRANGED IN GROUPS ACCORDING TO THEIR RELATIVE POLLUTION.

supplies, classified in six groups according to their relative pollution, as determined by inspection of the watersheds. Each group represents several different streams, and the results are based on weekly observations extending over a period of four years. As an indication of the varying degrees of contamination to which the waters are submitted, it may be stated that Group I includes only waters which are collected from almost uninhabited watersheds, while Group VI includes waters too much polluted to be safely used for domestic purposes, and the intermediate groups occupy relative positions between these two extremes. It will be observed from the diagram that the percentage of samples which had odors of decomposition, the average amounts of chlorine, free ammonia, nitrites, nitrates and the number of bacteria per c.c., show a general increase from left to right. The nitrogens are somewhat influenced by the presence of coloring matter and microscopic organisms, so that the sequence is not so regular as otherwise might be the case. It will be observed that the percentage of samples which gave typical positive tests for *Bacillus coli* with 1 c.c. show an increase from the unpolluted waters to the polluted waters, which corresponds well with the increase of bacteria, chlorine, and odors of decomposition, and with the known facts as to the pollution of the streams in question. None of the water supplies is polluted by the discharge of sewage which directly enters the stream; in all cases the pollution may be considered as indirect. Still more striking is the value of the presumptive test when applied to different amounts of water. This is illustrated in Table III.

TABLE III.

SHOWING THE PER CENT. OF SAMPLES WHICH GAVE POSITIVE TESTS FOR BACILLUS COLI WHEN DIFFERENT AMOUNTS OF WATER WERE EXAMINED. BASED ON WEEKLY OBSERVATIONS COVERING A PERIOD OF TWO MONTHS.

GROUP.	0.1 c.c.	1.0 c.c.	10 c.c.	100 c.c.	500 c.c.
I	0.0	3.5	20.8	50.0	50.0
II	5.0	7.3	15.0	60.0	60.0
III	0.0	7.0	50.0	50.0	60.0
IV	4.0	6.8	41.7	67.0	75.0
V	5.0	13.0	75.0	100.0	100.0
VI	5.0	20.2	75.0	80.0	100.0

From this it is seen that positive tests for *Bacillus coli* are obtained from watersheds that are practically unpolluted. Indeed, it has been my experience that practically all surface waters will give positive presumptive tests for *Bacillus coli* if sufficiently large quantities of water are tested. As the amount of pollution increases, the quantity of water necessary to give the positive reaction diminishes, until in very polluted waters the amount required may be but a fraction of a cubic centimeter. This has been shown by Dr. Jordan in his studies of the Chicago Drainage Canal, and by the Liverpool school of bacteriologists in England in their studies of sewage.

Just where to draw the line between "good" and "bad" waters cannot be said until the application of this method has been more widely extended, but as a provisional schedule of interpretation, the following is suggested, though with some hesitation and with the expectation that it will be modified by subsequent studies.

Sanitary Quality.	Presumptive Test for Bacillus Coli.				
	0.01 c.c.	0.1 c.c.	1.0 c.c.	10.0 c.c.	100 c.c.
Safe.	0	0	0	0	+
Reasonably safe.	0	0	0	+	+
Questionable.	0	0	+	+	+
Probably unsafe.	0	+	+	+	+
Unsafe.	+	+	+	+	+

It is to be remembered that this schedule refers to the presumptive test as made above, and not to the isolation of the bacillus by the more elaborate methods of sub-cultures. Furthermore, this test is not to be considered alone and as all-sufficient; it is to be treated as but one part of a sanitary analysis which includes a chemical as well as a biological examination, and the complete analysis must be used in making a final judgment upon the water. Comparisons of the results of positive tests with the rainfall on the watershed of the Brooklyn Water Supply show that a majority of the positive tests have occurred immediately after heavy rains, indicating that the pollution was washed into the streams from the surface—as is known to be the case. Moreover, studies of the seasonal distribution show that there is a tendency to increased numbers of posi-

tive tests in the spring and fall, when farmers are manuring their fields. Whether or not, therefore, this test indicates absolutely the presence of *Bacillus coli* in the water, it is certainly an indication of an inferior sanitary condition.

Positive Presumptive Tests for Bacillus Coli in Ground Water.

When a typical positive presumptive test is obtained for the presence of *Bacillus coli* in ground water, it is an almost infallible indication of the presence of contamination with surface water. The following may be taken as an illustration:

A certain driven well station was located in swampy land, along the shores of a stream, and the tops of the wells were so placed that they were occasionally flooded at times of high water. The water in the stream was objectionable from the sanitary standpoint. The wells themselves were more than 100 feet deep; they penetrated a clay bed and yielded what may be termed artesian water. Tests for the presence of *Bacillus coli* had invariably given negative results, as might be naturally expected. Suddenly, however, the tests became positive, and so continued for several days. On investigation it was found that some of the wells had been taken up to be cleaned, and that the workmen in resinking them had used the water of the brook for washing them down. This allowed some of the brook water to enter the system. It was also found that at the same time the water in the brook had been high, and because of the lack of packing in certain joints at the top of the wells, the brook water leaked into the suction main. The remedy was obvious, and was immediately applied, after which the tests for *Bacillus coli* once more became negative. During all this time the chemical analysis of the water was not sufficiently abnormal to attract attention. On another occasion, a water supply taken from a small pond fed by springs, and which was practically a large open well, began to give positive tests for *Bacillus coli*, and on examination it was found that a gate which kept out the water of a brook which had been formerly connected with the pond, was open at the bottom, although it was supposed to have been shut, thus admitting a contaminated surface water to the supply.

The methods which are in vogue in England for determining the presence of *Bacillus coli* in water cannot be considered as strict as those ordinarily employed in this country, and their results can be

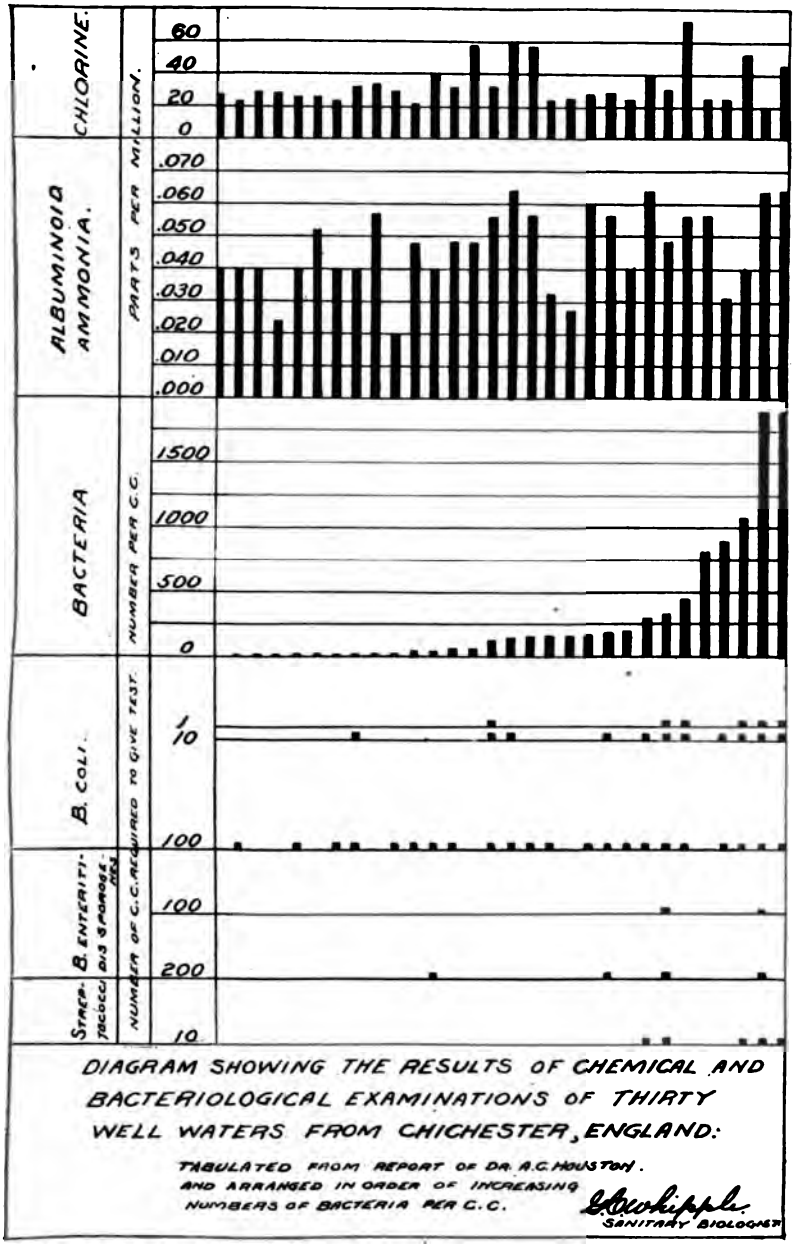

CHLORINE.
ALBUMINOID AMMONIA.
PARTS PER MILLION.
60
40
20
0
.070
.060
.050
.040
.030
.020
.010
.000
BACTERIA
NUMBER PER C.C.
1500
1000
500
0
B. COLI.
NUMBER OF C.C. REQUIRED TO GIVE TEST.
1/10
100
B. ENTERITIDIS SPORGES.
100
200
STREPTOCOCCUS
10
DIAGRAM SHOWING THE RESULTS OF CHEMICAL AND BACTERIOLOGICAL EXAMINATIONS OF THIRTY WELL WATERS FROM CHICHESTER, ENGLAND.
TABULATED FROM REPORT OF DR. A.C. HOUSTON.
AND ARRANGED IN ORDER OF INCREASING NUMBERS OF BACTERIA PER C.C.
G. C. Whipple
SANITARY BIOLOGIST

FIG. 2.

better compared with those of our presumptive tests than with the ultimate tests as made according to American methods. In the 30th Annual Report of the Local Government Board of Great Britain, there is an interesting report by Dr. A. C. Houston on "The Chemical and Bacteriological Examination of Chichester Well Waters." He gives a series of figures showing the results of chemical and bacteriological tests of a large number of open wells. These results are shown graphically in Figure 2, arranged in order of increasing number of bacteria. It will be seen from this table that there was little correspondence between the total number of bacteria and either the chlorine or the albuminoid ammonia, while the results obtained by the bacteriological examination seemed to hold together very satisfactorily. It will be noticed that there was a gradual increase in the number of *Bacillus coli* in the water from the left to the right of the diagram, thus corresponding with the increase in the total number of bacteria. The test for *Bacillus enteritidis sporogenes* and streptococci gave corresponding results.

Presumptive Test for Bacillus Coli as an Index of the Efficiency of Filtration.

The practical value of the presumptive test is also shown when used to determine the efficiency of filters. This has been well illustrated by the experiments made at Lawrence, Mass., by the State Board of Health, the results of which have been already presented to this Section. The following example, taken from the records of a test of a mechanical filter, is also of interest in this connection:

TABLE IV.

Showing the Results of Presumptive Tests for Bacillus Coli in Different Amounts of Water before and after Filtration through a Mechanical Filter.

Period.	Water.	Number of Samples.	Per Cent. of Positive Tests.			
			1 c.c.	10 c.c.	100 c.c.	500 c.c.
Filter working well.	Raw Water.	15	6.7	40.0	40.0	40.0
	Filtered Water.	15	0.0	0.0	7.0	6.7
Filter working badly.	Raw Water.	16	18.7	43.7	68.7	56.2
	Filtered Water.	16	31.2	50.0	37.5	56.2

For fifteen days, during which the filter was doing good work, as shown by the chemical analysis and by its removal of bacteria, 6.7% of the samples of raw water gave positive tests when tested with 1 c.c., while the per cent. of samples of filtered water which gave positive tests was 0. When tested with quantities of 500 c.c., 40% of the samples of raw water gave positive tests, and 6.7% of the samples of filtered water. During a period of sixteen days, when the filter was doing poor work, as shown by the chemical analysis and general appearance of the effluent, 18.7% of the samples of raw water gave positive tests in 1 c.c., while 31.2% of the samples of filtered water gave positive tests. When tested in quantities of 500 c.c., 56.2% of the samples of raw water gave positive tests, and 56.2% of the samples of filtered water gave positive tests. Thus, during the first period the filter was yielding a water which contained very few *Bacillus coli*, as determined by the presumptive tests, while during the second period the filtered water was no better than the raw water.

Summary.

The foregoing may be summarized as follows:

1. The methods necessary for the certain identification of *Bacillus coli* in water involve technique so complicated and so time-consuming that they are not practical as working tests in connection with the supervision of water supplies.

2. The fermentation of dextrose broth, as first suggested by Dr. Theobald Smith, furnishes the most rapid and most practical test for the presence of *Bacillus coli* in water.

3. The extension of this test to cover different quantities of water in the same samples, thus making the test quantitative (within limits) as well as qualitative, greatly enhances its value.

4. *Bacillus coli*, if not itself widely distributed in nature, resembles certain common bacteria in all points covered by the usual tests, to such an extent as to throw doubt upon the use of this organism as a conclusive test for fecal contamination.

5. But whether or not *Bacillus coli* is solely an intestinal germ, the presumptive test described above is a useful test to determine the sanitary quality of water, and is one which gives results that agree well with chemical and biological analysis.

Mt. Prospect Laboratory,
Brooklyn, N. Y.

A COMPARISON OF VARIOUS TESTS APPLIED TO PAINTS USED FOR THE PROTECTION OF IRON.

By AUGUSTUS H. GILL and CHARLES C. JOHNSON.

The necessary qualifications of a paint to prevent rust are: (1) That it shall be impervious to and unaffected by moisture or other atmospheric influences. (2) That it shall form a surface sufficiently hard to be durable and yet sufficiently elastic to conform to the expansion and contraction of the metal. (3) That it shall adhere firmly to the surface to which it is applied. (4) That it shall not corrode the metal to which it is applied.

Among the various practical tests for ascertaining the value of paints as a protection against rust are the following: (1) Loesner's steam test. (2) "The water and moisture test." (3) Immersion in water. (4) Test of the electrical insulation. (5) Heat test.

The object of this investigation was to make a comparative test of these different methods and to decide, if possible, whether the value of a paint when in actual use can be ascertained by any such laboratory experiments. This permitted, at the same time, a comparison of the various paints themselves.

The tests enumerated were carried out in the following manner:

Loesner's steam test.[1] — Strips of sheet iron are carefully cleaned upon an emery wheel and coated with two layers of paint, each layer being allowed to dry four days, care being taken in every case that the first coat was thoroughly dried before the second was applied. The strips are placed over the apertures of a constant-level water bath at the height of about 5 cm. above the water and supported upon strips of wood at each end to prevent abrasion. After 15 hours' exposure to the ascending steam, the paint is dried at 100°C., softened with aniline, and removed with a soft brush. The strips are dried with alcohol and their surfaces examined for rust. A paint

[1] Chem. Rev. Fett u. Harz Ind. **4**, 329.

is considered to be satisfactory which after 15 hours' exposure to the steam permits no rusting of the metal beneath it.

"*The water and moisture test*" is performed by painting the inner surface of a shallow iron dish, which has previously been cleaned by the sand blast, and exposing the paint to the action of slowly evaporating water. The water is allowed to evaporate to dryness at the ordinary temperature of the room, the dish refilled — usually once a week — and the evaporation repeated until the interior of the dish shows more or less rust. The condition of the surface is carefully examined before each refilling. The dishes used were 10 cm. in diameter and 2 cm. deep.

The next test, that of *immersion in water*, consists simply in exposing the painted iron strips to the continuous action of water. In this work the strips were placed in beakers 5 inches deep, so that the water level stood about $\frac{1}{2}$ an inch below the edge of the painted surface, the water being kept at approximately constant level.

The test of *electrical insulation* was made by preparing and painting the strips as in the other tests. A dam was made on each strip and filled with mercury, which served as an electrode and insured good contact between the pole and the paint coating. The dams were made by fastening rubber washers to the strips by means of wax; the remainder of the operation consisted in clamping one pole of a testing transformer to the bare metal and dipping the other pole into the mercury. Direct current is preferably used, although in these experiments an alternating current was employed. The voltage was increased until the insulation failed. This test indicates the relative continuity of the coatings, since a porous film will allow the current to pass through it readily.

The heat test was made by subjecting the paint to a temperature of 400° F. for two hours in an oven. That which offers the greatest resistance to heat is, so far as this test is concerned, the best paint. The heat promotes oxidation and produces in a few hours an effect similar to that which would be obtained very slowly at ordinary temperatures.

TABLE I. SHOWING THE BEHAVIOR OF VARIOUS PAINTS WHEN SUBJECTED TO LOESNER'S STEAM TEST.

PAINT.	APPEARANCE OF COATING OR METAL.
Dixon's graphite (2 tests).	Coating appeared rubber-like and could be scraped off easily; 8-10 medium-sized blisters formed.
Durable metal coating (2 tests).	Coating adhered well, but was somewhat porous.
Prince's mineral brown (2 tests).	Coating was covered with very small blisters which could be scraped off easily.
Bessemer (iron oxide) (2 tests).	Many blisters formed.
Raw linseed oil (applied hot).	Strip rusty.
Boiled linseed oil.	Strip corroded for half its surface.
Black enamel (2 tests). (tar)	Very large blisters formed; coating could be brushed off very easily.
Red lead 78%, raw oil 22%.	Somewhat porous; condition good.
Red lead 78%, raw oil 22%.	Condition good.
Red lead and lucol * (2 tests).	Condition good.
Red lead 30%, raw oil 10%, white lead 60% (2 tests).	Very small blisters formed; condition good.
First coat red lead, second coat white lead (2 tests).	Small blisters formed; condition good.
Red lead 56%, white lead 28%, raw oil 16% (2 tests).	Coating full of pores and small blisters.
Barytes 86%, boiled oil 14% (2 tests).	Coating full of pores and small blisters and could be easily scraped off.
Red oxide of iron and raw oil (2 tests).	Coating very tender and could be easily scraped off.
Zinc oxide and raw oil (2 tests).	Coating tough and in good condition, appeared rubber-like and shrivelled.
Zinc white 51%, barytes 38%, raw oil 11% (2 tests).	Coating porous.
White lead 60%, zinc oxide 30%, raw oil 10% (2 tests).	Condition good.
White lead and raw oil (2 tests).	Small blisters formed in coating.
White lead and lucol (2 tests).	Small blisters formed in coating.
White lead 57%, barytes 43%, raw oil (2 tests).	Coating blistered.
First coat red lead, second coat graphite.	Coating somewhat porous and covered with small blisters.
First coat red lead, second coat red oxide.	Covered with very small blisters.
As the preceding, using lucol (2 tests).	Covered with very small blisters.
Pure rosin varnish (2 tests).	Coating nearly all removed.
Half rosin and half kauri varnish (2 tests).	Coating adhered very well, but blistered considerably.
Pure kauri varnish.	Coating covered with small blisters.
Suspected varnish.	Very small blisters formed.

* Lucol is said to be a mixture of about equal parts of a light mineral oil with fish oil which has been treated with sulphur chloride; this is used as a substitute for linseed oil.

TABLE II. SHOWING THE BEHAVIOR OF VARIOUS PAINTS UNDER THE "WATER AND MOISTURE TEST."

PAINT.	TIME OF EXPOSURE IN DAYS.	APPEARANCE OF COATING OR METAL.
Dixon's graphite.	7	A few very small blisters.
	36	Covered with very small blisters.
Durable metal coating.	28	Condition good.
	36	General condition good; a few rough patches formed.
	53	A few small rust spots.
	61	Covered with small blisters.
Prince's mineral brown.	12	Covered with small blisters.
	57	Covered with small blisters.
Bessemer.	17	Condition good.
	26	Small blisters formed.
	40	Covered with blisters.
	49	Corroded.
Raw linseed oil.	11	Slightly corroded.
	32	Corroded.
Boiled linseed oil.	9	Like rubber.
	17	Corroded.
	28	Rusty.
Red lead, raw oil.	61	Condition good.
Red lead, lucol.	46	Condition good.
Red lead 30%, white lead 60%, raw oil 10%.	36	Condition good.
First coat red lead, second coat white lead.	36	Condition good.
Barytes, boiled oil.	7	Covered with small blisters.
	28	Corroded.
Red oxide of iron, raw oil.	22	Condition good.
	33	Corroded at edge.
	46	Small blisters.
	60	Corroded on sides of dish.
Red oxide of iron, boiled oil.	11	Covered with small blisters.
	36	Partly corroded.
Zinc white, raw oil.	12	A few rust spots.
	34–49	Rust spots increased in size.
White lead, zinc oxide, raw oil.	12	Several spots of rust.
	23–49	Rust spots increased in number.
White lead, lucol.	10	Condition good.
	18	Specks of rust.
White lead, raw oil.	16	Condition good.
	26	Small specks of rust.
Rosin varnish.	11	Several spots of rust.
	34	Most of coating white.
	45	Covered with blisters.
Rosin and kauri varnish.	9	Part of coating white.
	20	Somewhat blistered.
	41	Covered with small blisters.
	53	Partly corroded.
Pure kauri varnish.	11	A few spots of rust.
	34	Partly corroded.
	45	Corroded and covered with small blisters.
Suspected varnish.	9	Covered with specks of rust.
	30	Covered with small blisters.
	41	Corroded.

TABLE III. SHOWING THE BEHAVIOR OF VARIOUS PAINTS UNDER THE "IMMERSION IN WATER TEST."

PAINT.	TIME OF IMMERSION IN DAYS.	APPEARANCE OF COATING OR METAL
Dixon's graphite.	40	Covered with small blisters.
Durable metal coating.	40	Covered with medium-sized blisters.
Prince's mineral brown.	40	Quite tough; covered with small blisters.
Bessemer.	40	Covered with large blisters.
Raw linseed oil.	40	Corroded; small blisters.
Boiled oil.	40	Corroded.
Red lead, raw oil.	40	Condition good.
Red lead, lucol.	25	Coating tender.
Red lead 30%, white lead 60%, raw oil 10%.	25	Condition good; coating tough.
First coat red lead, second coat white lead.	25	Condition good; coating tender.
Barytes, boiled oil.	40	Covered with small blisters; coating quite tough.
Red oxide of iron, raw oil.	40	Covered with small blisters; coating tender.
Red oxide of iron, boiled oil.	25	Covered with small blisters.
Zinc white, raw oil.	40	Covered with rust spots; coating quite tender.
White lead 60%, zinc white 30%, raw oil 10%.	40	Several rust spots; coating quite tender.
White lead, lucol.	25	A few small rust spots; coating quite tough.
White lead, raw oil.	40	A few small blisters; coating tender.
White lead 57%, barytes 33%, raw oil 10%.	25	Condition fair; coating quite tender.
Rosin varnish.	15	Covered with large blisters.
Rosin and kauri varnish.	15	Covered with large blisters.
Suspected varnish.	15	Corroded at surface of water.
Kauri varnish.	15	Covered with small blisters.

TABLE IV. TEST OF ELECTRICAL INSULATION.

PAINT.	VOLTAGE AT WHICH COATING FAILED.	AVERAGE.
Dixon's graphite.	<300	<300
Durable metal coating.	440, 650, 550	547
Prince's mineral brown.	700, 550, 650	633
Bessemer.	<300	<300
Black enamel.	<300	<300
Barytes, boiled oil.	670, 450	560
Red lead, raw oil.	1700, 1680, 1740	1707
Red lead, lucol.	300, 520, 450, 480	438
First coat red lead, second coat white lead.	790, 1060, 700	850
Red lead 56%, white lead 28%, raw oil 16%.	600, 480, 1100	727
Red lead 30%, white lead 60%, raw oil 10%.	700, 720, 560	660
Red oxide, raw oil.	<300	<300
Boiled oil.	<300	<300
First coat red lead, second coat red oxide.	930, 950, 870	917
First coat red lead, second coat graphite.	500, 620, 600	573
Zinc white, raw oil.	660, 610, 620	630
White lead 60%, zinc white 30%, raw oil 10%.	750, 580, 480	603
Zinc white 51%, barytes 38%, raw oil 11%.	860, 550, 680	697
White lead, raw oil.	650, 340, 540	510
White lead, lucol.	810, 810, 860	827
White lead 54%, barytes 40%, raw oil 6%.	630, 650, 970	750
Red lead, raw oil.	760, 640, 540	647
Prince's mineral brown.	710, 820, 700	743
Lucol oil.	<300	<300
Suspected varnish.	620, 900, [2600], 600	707
Rosin varnish.	580, 520, 520	540
Rosin and kauri varnish.	410, 380	395
Kauri varnish.	420, 370	395

TABLE V. HEAT TEST. TEMPERATURE 400°F. TIME 2 HOURS.

PAINT.	APPEARANCE.
Dixon's graphite.	Condition good.
Durable metal coating.	Small cracks on surface; coating adhered well.
Prince's mineral brown.	Condition good.
Bessemer.	Condition good.
Barytes 86%, boiled oil 14%.	Came off in scales.
Black enamel.	Brittle; peeled off.
Red lead 78%, raw oil 22%.	Brittle; peeled off.
Red lead 30%, white lead 60%, raw oil 10%.	Brittle; peeled off.
Red lead 78%, lucol 22%.	Brittle; peeled off.
First coat red lead, second coat white lead.	Brittle; peeled off.
Red lead 56%, white lead 28%, raw oil 16%.	Brittle; peeled off.
Red oxide, raw oil.	Condition good.
Red oxide, boiled oil.	Condition good.
Zinc white, raw oil.	Peeled off.
Zinc white 51%, barytes 38%, raw oil 11%.	Very good.
White lead 60%, zinc white 30%, raw oil 10%.	Brittle.
White lead, lucol.	Peeled off.
White lead, raw oil.	Blistered: peeled off easily.
White lead 54%, barytes 40%, raw oil 6%.	Peeled off.
Rosin varnish.	Peeled off.
Rosin and kauri varnish.	Condition good; coating tough and elastic.
Kauri varnish.	Condition good; coating tough and elastic.
Suspected varnish.	Condition good; coating tough and elastic.
Lucol.	Condition good.
First coat red lead, second coat graphite.	Peeled off.
First coat red lead, second coat red oxide.	Peeled off.

Table VI. Summary of Tests.

Paint.	Lorsner.	Water and Moisture.	Immersion.	Electricity.	Heat.
Dixon.	Attacked.	Attacked.	Slightly attacked.	<300	Not attacked.
Durable metal.	Slightly attacked.	Not attacked.	Slightly attacked.	547	Cracked.
Mineral brown.	Attacked.	Slightly attacked.	Slightly attacked.	633 743	Not attacked.
Bessemer.	Attacked.	Very much attacked.	Attacked.	<300	Not attacked.
Raw oil.	Very much attacked.	Very much attacked.	Very much attacked.	—	——
Boiled oil.	Very much attacked.	Very much attacked.	Very much attacked.	<300	——
Black enamel.	Very much attacked.	——	——	<300	Brittle; peeled off.
Red lead.	Not attacked.	Not attacked.	Not attacked.	1707 647	Brittle; peeled off.
Red lead and lucol.	Attacked.	Not attacked.	Not attacked.*	438	Brittle; peeled off.
Red lead 30%, White lead 60%.	Slightly attacked.	Not attacked.	Not attacked.	660	Brittle; peeled off.
First coat red lead, Second coat white lead.	Slightly attacked.	Not attacked.	Not attacked.*	850	Brittle; peeled off.
Barytes and boiled oil.	Attacked.	Attacked.	Slightly attacked.	560	Peeled off.
Oxide iron.	Attacked.*	Slightly attacked.	Slightly attacked.	<300	Not attacked.
Zinc white.	Somewhat attacked.	Attacked.	Attacked.*	630	Peeled off.
Zinc and barytes.	Attacked.	——	——	697	Not attacked.
White lead and zinc.	Not attacked.	Attacked.	Attacked.*	—	Brittle.
White lead.	Slightly attacked.	Slightly attacked.	Slightly attacked.*	510	Peeled off.
White lead and lucol.	Slightly attacked.	Slightly attacked.	Slightly attacked.	827	Peeled off.
Lead and barytes.	Attacked.	——	Attacked.*	750	Peeled off.
Red lead and graphite.	Slightly attacked.	——	——	573	Peeled off.
Red lead and red oxide.	Slightly attacked.	——	——	917	Peeled off.
Red lead, red oxide and lucol.	Slightly attacked.	——	——	—	——
Rosin varnish.	Very much attacked.	Attacked.	Very much attacked.	540	Peeled off.
Half rosin varnish.	Attacked.	Slightly attacked.	Very much attacked.	395	Not attacked.
Kauri varnish.	Slightly attacked.	Slightly attacked.	Slightly attacked.	395	Not attacked.

*Coating tender.

A comparison of the tests, Table VI, would seem to show that the results obtained by the Loesner test agree well with the "water and moisture" and "immersion in water" tests; these, in turn, agree well with the results obtained in practice. As was to be expected, they do not agree with the results of the heat test.

Considering the various paints themselves, it is evident from these tests that the paints which best withstand the action of water or atmospheric agencies are those which are most attacked by heat, and *vice versa.*

These are, in order of most resistance: Red lead; red and white lead mixed, or first coat red lead and second coat white lead; durable metal coating; white lead; the iron oxide paints, or the above paints mixed with ground barytes. It should, however, be borne in mind, in this connection, that a longer time for drying of the painted strips would have been desirable, but it was impossible to give it. The shortness of time is particularly favorable to the lead paints.

For the most complete protection of iron it would seem to be essential to use a paint in which the pigment combines with the oil, as with the lead paints, or a varnish carrying pigment. These tests well show how inefficient a protection is linseed oil without a pigment.

Three varnishes were tested at the same time, pure kauri, half kauri and half rosin, and pure rosin; their protecting power was in the order here given, the kauri standing the tests the best.

THE HANGING VALLEYS OF GEORGETOWN, COLORADO.

By W. O. CROSBY.

GEORGETOWN is situated in the valley of Clear Creek, a tributary of the South Platte draining the eastern slope of the Main Range in the latitude of Gray's Peak, in the county of Clear Creek, 50 miles by both creek and railroad from Denver, and at an altitude of 8,500 feet. The town lies at the northern foot of Leavenworth Mountain (Figure 1) which, continued above timber line in McClellan Mountain, divides the main stream from the important tributary known as Leavenworth Creek. Below Leavenworth Mountain the trend of the valley is northward for about two miles, between the long, straight ridge of Griffith and Saxon Mountains on the east and the slightly divided Republican, Democrat, and Columbia Mountains on the west, to the foot of Empire Pass, where Columbia Mountain is connected with Douglas Mountain by a low, sharp ridge. At this point a long detrital cone, heading in a prominent gulch on Saxon Mountain, obstructs the drainage across the entire breadth of the valley. Below this obstruction the bottom of the valley is narrow, with little or no level land, and the stream falls rapidly as it winds around the base of one detrital cone after another; but above it, to the upper end of Georgetown and the base of Leavenworth, the valley floor is approximately level for a breadth of 1,000 to nearly 2,000 feet, suggesting the silted-up bed of a temporary lake, above which the mountains rise abruptly 3,000 to 4,500 feet. Up stream the north-south course of this part of the valley is continued in the valley of Leavenworth Creek, between Independence Mountain on the east and Leavenworth Mountain on the west, as far as the beautiful morainal lakelets known as Green Lake ($2\frac{1}{2}$ miles) and Clear Lake (3 miles) and beyond; while Clear Creek, above Georgetown, swings in a graceful curve to its normal westerly course before reaching Silver Plume ($2\frac{1}{2}$ miles) and holds this course to its source in the Snowy Range.

The interest of this paper centers in the relations of these two valleys to that part of the main valley immediately below Leaven-

FIG. 1.—PANORAMIC VIEW OF THE GEORGETOWN VALLEY, SHOWING ITS ABRUPT TERMINATION AGAINST THE NORTHERN FACE OF LEAVENWORTH MOUNTAIN, WITH THE HANGING VALLEY OF LEAVENWORTH CREEK ON THE LEFT AND OF CLEAR CREEK ON THE RIGHT.

worth Mountain and occupied by Georgetown, nearly the entire field of the study being shown in Figure 1. Below the high moraines enclosing Green and Clear Lakes, the valley of Leavenworth Creek is wide and its gradient low, the stream meandering somewhat across its approximately base-levelled floor. As it approaches Georgetown, however, the creek begins to trench the floor of this mature mountain valley and, falling about 700 feet in the last mile, it escapes abruptly into the still broader Georgetown valley, through the deep V-shaped gorge shown in Figure 2, and less distinctly in Figure 1. The general relations of the two valleys are well expressed in Figure 1, which affords an excellent transverse profile of the upper valley and shows it ending abruptly downward in a steep and almost precipitous slope, and thus clearly holding the relation of a hanging valley to the lower valley.

The main problem, of course, lies in the significance of this break between the two valleys; and three general explanations demand consideration — fluvial erosion, glacial erosion, and displacement.

Obviously the floor of the valley of Leavenworth Creek was once continuous with the floor of Clear Creek Valley. The first explanation of the existing discordance, or lack of continuity, would mean that Clear Creek has, in later times, lowered its bed more rapidly than Leavenworth Creek, by virtue, we may suppose, of the advantage which, during the elevation of the range, a main stream would enjoy in experiencing acceleration more promptly than its lateral or right-angled tributaries. This is an important principle, and fully competent, no doubt, to explain many hanging valleys; appearing, for example, to account perfectly for the hanging tributaries of the upper San Joaquin River in California. But the conditions at Georgetown are clearly unfavorable to its application, since the escarpment in which both the valley and gorge of Leavenworth Creek terminate is in the lee of Leavenworth Mountain with reference to the direct and normal course of Clear Creek, and cannot possibly be regarded as due to the erosive action of the latter. The hypothesis of more vigorous glacial erosion in the main valley, appealed to by Davis and others in explanation of some of the hanging valleys of the Alps, and more recently of other districts, is beset by still greater difficulties here; for I have failed to find below Leavenworth Mountain any evidence of glaciation. The mountain slopes are here wholly unglaciated, and all apparent moraines are really detrital cones heading in lateral gulches,

forcing the creek against the base of the opposite slope and thus causing it to meander in spite of its rapid fall. But even granting that the glacier of the Clear Creek Valley did cross the site of Georgetown, the salient northwestern angle or spur of Leavenworth Mountain would prove a still more serious obstruction than before; nor could we appeal with more success to the phenomena of the bergschrund, for surely this basin, a dozen miles from the heads of the valleys in the Snowy Range, was never an amphitheatre of névé; on the contrary, we must think of it as in any case near the lower limit of glaciation and well below the line above which the formation of glacial ice or its firm adhesion to the bounding rocks is possible.

We have next, then, to inquire whether the facts are more favorable to the displacement hypothesis. In this connection some of the vein phenomena of the district are significant. Traversing the lower slope of Griffith Mountain, to the north of Leavenworth Creek, is the Griffith lode, which may be regarded as virtually continuous to the south and southwest with the lode system of the Alaska, Centennial, Burrell, and Big Indian Mines, crossing the mouth of Leavenworth Gulch just below the escarpment and traversing the northern face of Leavenworth Mountain to and through the prominent notch high up on its northwestern spur. The workings of the Centennial Mine, with a depth of 600 feet and a length of over 1,500 feet, extend directly across the mouth of Leavenworth Gulch and reveal perfectly the character of the fissure at this most critical point. Here, as throughout its course, it is an approximately plane, vertical, and vertically striated wall, characterized at most points by a clay gouge from six inches to a foot or more in thickness, and by more or less extensive sheeting of the granitic complex, as well as by frequent oblique breaks, or branch fissures, in which the filling of quartz and ore chiefly occurs. A more ideal fault fissure it would be difficult to imagine; and that the movement has been in part geologically recent is indicated by certain features of the Griffith and neighboring mines to which my attention has been directed by Mr. J. S. Randall, of Georgetown. For a length of a mile or more along the lower slope of the mountain the country rock is in a shattered condition, so that very little continuously solid rock is found, even at a depth of hundreds of feet, the structure being so open at some points as to permit a free circulation of air through

the ground. Undoubtedly the fissure system and the veins antedate the modern escarpment, at least in the main; but that there has been comparatively recent movement along this line is unquestionable; and of this the unlithified selvage, and not uncommon brecciation of the vein contents, with deposition of cryptocrystalline secondary quartz, are evidence.

There is evidence in the vein developments and in the breaks of the northwestern spur of Leavenworth Mountain that the fissure system divides in this mountain, a more northerly branch following and defining the northern base of the mountain and thus determining the abrupt and square southern end of the Georgetown Valley. A fracture system, which might be regarded as either a southward continuation or a repetition of the main Griffith-Centennial line, traverses the eastern slope of Leavenworth Mountain. It is well exposed for study in the extensive workings of the Aliunde Mine, and is seen to be characterized by a dike of porphyry, the geological recency of which is indicated by its broad margins of obsidian. The dike probably postdates the ore development, in the main, but the indications of movement subsequently to the formation of the dike are also very plain; and the downthrow is here quite clearly to the east and not to the west, although still on the side towards the valley. The chief topographic indication of this displacement is found in the dislocation of the tributary valley of Argentine Creek, which thus holds the relation of a hanging valley to the valley of Leavenworth Creek. In this instance the creek has notched its escarpment less deeply and, falling several hundred feet in a small fraction of a mile, develops the water power utilized in the operation of the Aliunde Mine. That the displacement at the foot of Leavenworth Gulch is not measured in its entirety by the height of the escarpment, as shown in Figure 1, is proved by the fact that while the Dewey & Wheeler concentrating mill, which is the point of view for Figure 2, stands on bed rock, which was blasted to prepare the foundation, a shaft about 100 feet from the mill, on the north side of Fourth Street, reached bed rock only at a depth of 125 feet. West of this a second shaft (now filled up) was sunk in 1870, near the corner of Rose and Third Streets in Georgetown, where the surface is approximately 50 feet lower (the first shaft starting on the detrital cone originating in Leavenworth Gulch), and not more than 150 feet from the steep base of Leavenworth Mountain, reaching

bed rock at a depth of 75 feet. Half a mile to the northward, and close against the base of Griffith Mountain, near the mouth of the lower tunnel, a shaft reached bed rock at 60 feet; and a short distance north of this, near the present base of the high dump of the main Griffith Tunnel, and possibly not over 100 feet from the base of the mountain, a well was sunk in early days to a depth of about 100 feet without reaching bed rock.

FIG. 2. — VIEW LOOKING UP THE GORGE OF LEAVENWORTH CREEK.
The sky-line on the right shows, in profile, the original, base-levelled floor of the valley.

In view of these facts, it can hardly be doubted that the part of the valley occupied by Georgetown is a depressed fault block, or graben, and that the valley is due in part to displacement and not wholly to erosion, thus suggesting comparison with Yosemite Valley. This view calls for another and complementary fault along the west side of the valley, at the base of Republican Mountain, and of its existence we have ample evidence, although in this instance the displacement is not close against the mountain. The confluence of the two creeks is not near the foot of Leavenworth Mountain, as would

be most normal, but half a mile or more to the northward; and as a specially interesting and puzzling feature in the topography of Georgetown we have the narrow ridge of granite extending north from the northwestern corner, or spur, of Leavenworth, separating Clear Creek from the level plain on which the main part of the town is built and terminating abruptly in the bold knob on which formerly stood the brick stack of Hall's reduction works. This knob

FIG. 3. — VIEW FROM HALL'S LEDGE LOOKING UP THE VALLEY OF CLEAR CREEK, WITH THE DEVIL'S GATE GORGE IN THE MIDDLE DISTANCE.

The low ridge of granite in the foreground separates the bed of Clear Creek on the right from the relatively low plain on which the main part of Georgetown is built.

or ledge is the point of view for Figure 3, which shows the ridge of granite bordered by the bed of Clear Creek on the right and connecting upward on the left with the angle of Leavenworth Mountain. On the west side of this ridge, which at the lowest points is not more than 5 feet above the creek, the latter actually or practically flows on the bed rock surface, while on the east side the level gravel floor of the valley is 10 or 12 feet, and the bed rock floor 85 or 90 feet, below the level of the creek. Obviously the east side of this ridge is on a fault with the downthrow to the east, run-

ning straight up the north face of Leavenworth Mountain, intersecting the oblique and east-west faults previously described and giving the northwestern angle of the mountain its salient character. The ridge just described, terminating in Hall's Ledge, is clearly only a narrow remnant of the gradually tapering north end of Leavenworth Mountain, which, we may or must believe, once separated the two creeks. Accepting this view, the displacement of the bed rock surface is probably not less than 100 feet; and the most anomalous feature is seen in the fact that the creek is left on the upthrow side for one-third of a mile after entering the Georgetown basin. Sedimentation in this basin has virtually obliterated the fault as a topographic feature of the valley floor and destroyed the water power to which it gave rise. Were the valley cleared of detritus, the part of the valley of Clear Creek above the fault would become a hanging valley in its relation to the Georgetown basin, or graben, or that part of the valley below the fault.

Under existing conditions, however, and in spite of the accumulated detritus below the main fault just described, the floor of this valley is abnormally elevated for a short distance, where it is trenched by the gorge, some 75 feet in depth, known as the Devil's Gate (Figure 3). The part of the valley above the Devil's Gate, which may conveniently be designated the Silver Plume Valley, is, aside from the morainal deposits which terminate half a mile or more above the Devil's Gate, flat-bottomed and free from a gorge down to the beginning of the Devil's Gate, where the rocky floor is abruptly uplifted at least 75 feet. In other words, local movement, or block faulting between two of the fractures crossing the northern face of Leavenworth Mountain, has raised a rock dam across the valley here approximately 75 feet high and 500 to 800 feet broad up and down the valley. Through this dam the stream has cut its gorge; and the absence immediately above this barrier of stratified deposits or any evidence of a lake is a plain indication that the elevation was gradual, and so slow that the stream kept pace with the movement. The former course of Clear Creek across this elevated tract can be traced along the line of the railroad east of the gorge in the waterworn ledges and pot-holes and well-rounded and waterworn gravel and bowlders identical with those of the modern stream bed, in which pot-holes are also forming. Farther up this valley we have similar and equally clear evidence of geologically recent faulting

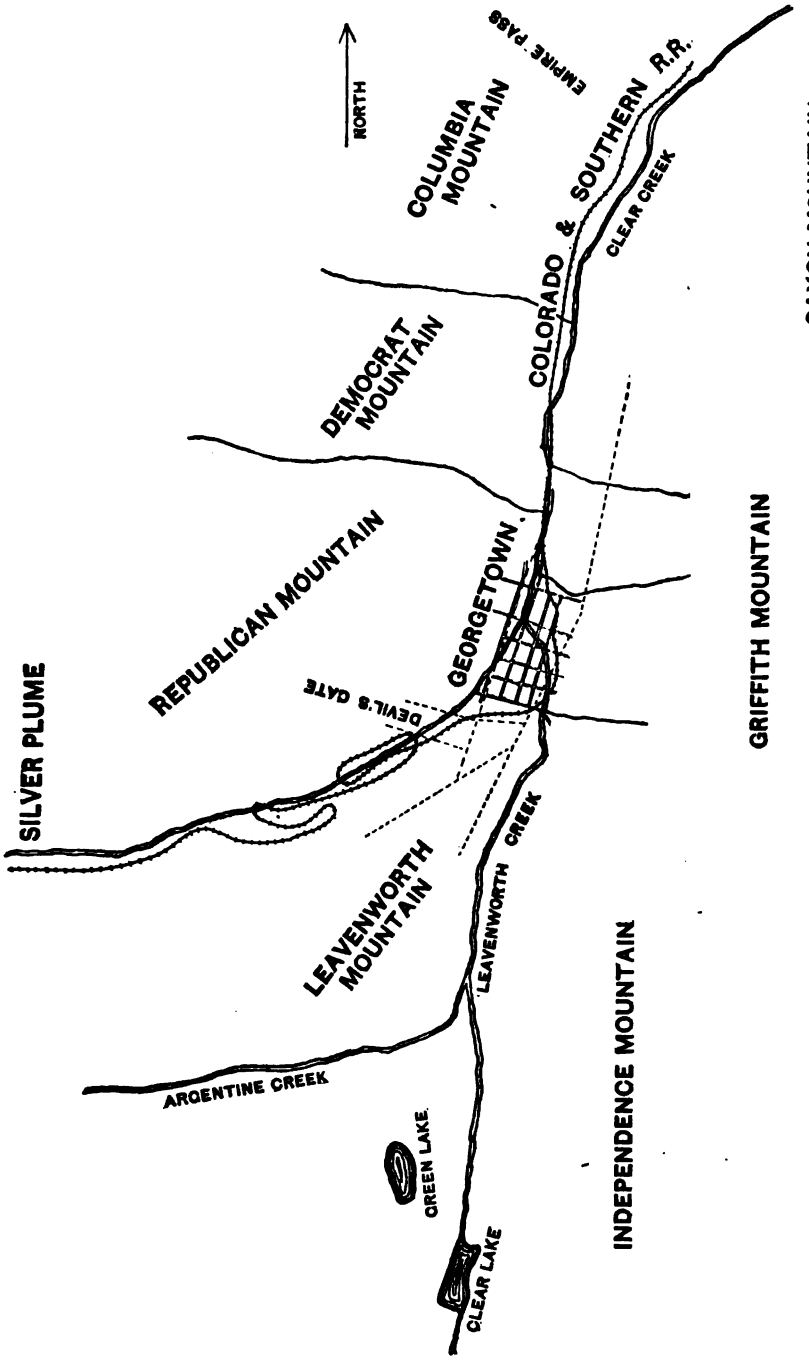


FIG. 4. — MAP OF GEORGETOWN AND VICINITY.

The broken lines show the probable locations of faults defining the Georgetown graben. Scale: one inch = about 4,000 feet.

in the immense semi-detached block of Sherman Mountain, rising precipitously from the north side of the valley between the village of Silver Plume and the group of rich mines, in the workings of which the fault fissures have been extensively and clearly developed and repeat the phenomena of the Aliunde Mines on the eastern slope of Leavenworth Mountain.

Taking a broader view of these phenomena, it appears improbable that they are peculiar to this district, but rather that they are characteristic of many of the drainage systems of the mountains, especially towards the headwaters and the axis of the range. The idea is inevitably suggested that the elevation of this great mountain mass, the broadest and possibly one of the oldest of the Colorado ranges, has been recently, and may be still in progress; and that while in the past the movement has been chiefly massive, developing the magnificent fault scarp overlooking the plains, it has in later times affected the axis more than the margin of the orographic block, leading to a marked tilting of the Cretaceous peneplain represented by the broad, grassy uplands or shoulders (alps) of the mountains; and in part, at least, the uplift is very locally differential and, in the Georgetown instance, in a way to accentuate the topography.

BOOK REVIEWS.

Gas Analysis.

Methods of Gas Analysis. By Dr. Walther Hempel. Translated from the third German edition and considerably enlarged by L. M. Dennis. New York: The Macmillan Co. 1902. Price, $2.25.

This makes practically a fourth edition of Hempel's well known and compendious work upon the subject. Some hundred pages have been added, including new methods of collecting and keeping gas samples, the use of the Orsat and Bunte apparatus, of the determination of combustible gases and the separation of argon from the air. The analysis of acetylene gas, of the gases produced by bacteria, or evolved in the electrolysis of chlorides and in the manufacture of bleaching powder, is detailed quite fully.

Especially valuable additions are the descriptions of an apparatus for the determination of the heating power of small quantities of gas; of a flame calorimeter for the determination of the calorific power of gases by the height of a flame, like the gas works' photometer; of the "gas lantern," an apparatus for controlling gas processes and inspecting heating plants. A chapter has been included upon the volumetric determination of carbon in steel.

In common with many foreign treatises, work done in other countries has been overlooked; one seeks in vain for mention of the work of Campbell and Hart upon the absorption of hydrogen by palladium chloride, or of that of Clowes on the absorption of oxygen by potassium pyrogallate, and of others.

There are, too, several statements and operations which are open to serious question: for example, in the method of sampling gases, an iron tube is used for temperatures above 300°. Moissan and also Fischer have shown that ferric oxide is reduced by carbonic oxide at 350° and higher; when this takes place the analysis would, of course, give an utterly false impression of what is transpiring within

the furnace. A method for the estimation of nitrogen trioxide is given, although according to Lunge and Pörschner this gas does not exist. With the Hempel calorimeter, coal is compressed into cylinders for combustion. The statement might have been added that this is impracticable for anthracites and for many samples of American bituminous coals.

The subject of the practical application of gas analysis to chimney gases is dismissed with too little detail. Although the primary object of the book is to describe Hempel's apparatus and methods, an important apparatus like the gas calorimeter of Junkers need not have been omitted.

The index could be enlarged to advantage in this and the German editions. A. H. GILL.

Steam Power Plants, Their Design and Construction. By Henry C. Meyer, Jr. New York: McGraw Publishing Co. 1903. $2.00.

This book is the assemblage and amplification of a series of articles which originally appeared in the *Engineering Record*, and which were written with the idea of giving the purchasers of boilers, engines, and other parts of steam power plants some idea of their problems, whether their problems were approached with the aid of a consulting engineer, or with nothing more than a business man's common sense and general information.

That the author apprehends the dangers and difficulties of the situation is shown by his opening sentence: "No better service can be done the non-expert about to construct a steam plant than to advise him to engage at the outset of the project some capable engineer to design the plant and superintend its installation." If the non-expert will heed this advice, the book cannot do any harm and is likely to do much good. The purchaser will undoubtedly better understand his expert and will be better able to decide on the business side of the transaction, which must, first or last, be decided by the purchaser. There is much, also, that may be profitably read by engineers, and some things that are not usually found in manuals and text-books on engines and boilers.

Another bit of good advice is that the intending purchaser of a small steam outfit shall go to some builder of good repute and, after stating his case, take what is given him; this will include a considerable amount of free expert advice, which in general will be good and not too much biased by the interest of the seller.

After giving such sound advice, one wonders why the author should include tables of dimensions of boilers, proportions of riveted joints, and standard pipe-fittings. These give the information required by the designer of an engine or boiler and not by the purchaser; and the designer has much fuller information than can be included in such a book. It also appears remarkable that our old friend, the formula for the thickness of a thin hollow cylinder, should be credited to the inspection department of the city of Philadelphia. But, after all, this array of technical information may deter the non-expert from entering too lightly into engine and boiler design.

Among the many features to be commended are samples of specifications for engines and boilers and other appliances, together with information concerning the customary way of arranging these matters. A number of minor, and yet important, matters may be noted, for example, that the builder or bidder should be notified if there is a traveling crane or other facility for handling and erecting machinery, in order that he may take account of it in making his bid.

Chapters to be especially commended are those on piping and handling coal; here there is the maximum of common sense with a minimum of expert information, and a business man may readily understand the greater part of the matter presented. In contradistinction, it is difficult to see what such a man can get from the chapter on chimneys, unless it may be the opinion that they are expensive and both difficult and uncertain in design. It is to be regretted that the author did not quote tables of sizes (such as are given by Kent and others) instead of formulæ, which are somewhat difficult to use, and in the hands of the non-expert may lead to absurd results; in the tables such absurdities are carefully omitted. Exception should be taken to the statement that a mechanical stoker can be run by firemen of ordinary intelligence; it is more proper to say that these appliances always work well in the hands of experts sent out by the makers, and frequently fail because they are afterwards run without sufficient intelligence. In the book are a number of illustrations to explain methods and details, and also a number of excellent plates

showing large and well-arranged steam plants, *without* explanation. They are interesting and much can be learned from them without explanation, but it is a question whether they will not be a disappointment to the class for which the book is primarily intended.

Science Abstracts, Physics and Electrical Engineering. London: Feilden Pub. Co. New York: International News Co. Monthly. Subs. $7.50; single section, $4.50 yearly.

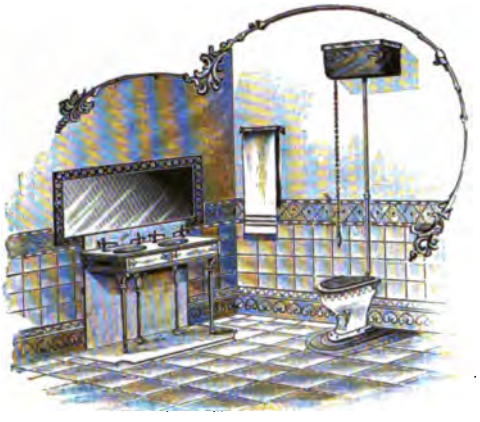
All who are interested in the science of Physics in its various branches, or are concerned with the application of physical principles to engineering problems, know that English "Monatsbericht," *Science Abstracts*, and recognize its value as a source of information in regard to the work being done in this field. The announcement of a change in the plan of publication will be received, therefore, with considerable interest.

This journal was published first in 1895 as a supplement to the Proceedings of the Physical Society of London, under the title, "Abstracts of Physical Papers from Foreign Sources." In 1898, the first volume under the present title was issued, and the scope of the publication was extended to include electrical engineering. It became at that time a partially independent journal, published under the direction of a joint committee from the Institution of Electrical Engineers and the Physical Society of London. The responsible editor is now G. W. de Tunzelman, and the journal is entering upon its sixth year of publication.

It will in future be published in two sections: *Section A*, Physics, embracing light (including photography), heat, sound, electricity and magnetism, chemical physics and electro-chemistry, general physics, meteorology and terrestrial physics, and physical astronomy; and *Section B*, embracing steam plant, gas and oil engines, automobiles, oil engine driven ships and launches, balloons and airships; general electrical engineering, including industrial electro-chemistry, electric generators, motors and transformers, electrical distribution, traction and lighting, and telegraphy and telephony. The subscription price will be eighteen shillings, or four and a half dollars, for each section

separately, including index; for the two sections thirty shillings, or seven and a half dollars.

The American Physical Society is now joined with the Institution of Electrical Engineers and the Physical Society of London in the direction of the publication, and has elected Professor E. H. Hall of Harvard University as its representative on the publishing committee. In consequence of this arrangement, Section A will in future be received by all members of the American Physical Society. The American Institute of Electrical Engineers is also co-operating with the committee and taking special means to bring the publication to the notice of all their members, who will in future be able to obtain it at a reduced subscription rate through the secretary of the American Institute.



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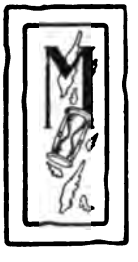

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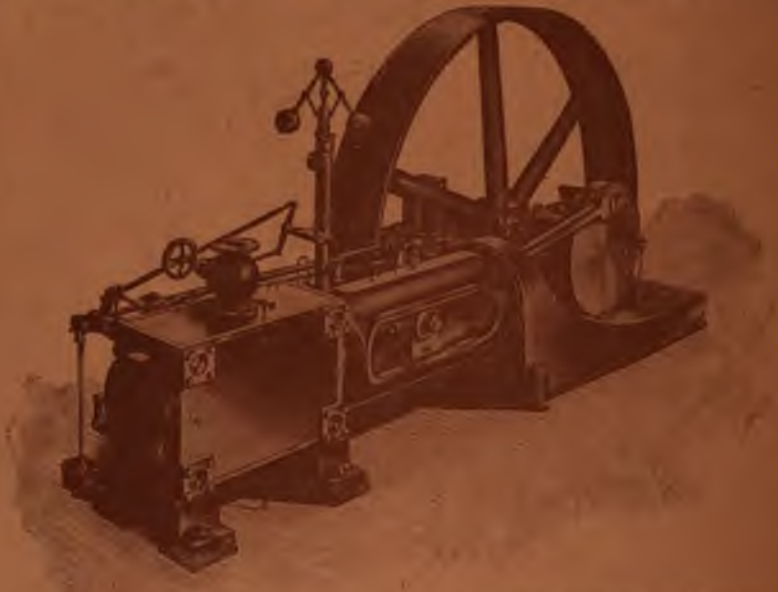

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TECHNOLOGY QUARTERLY

AND PROCEEDINGS OF THE SOCIETY OF ARTS

JUL 8 1903

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AND

PROCEEDINGS OF THE SOCIETY OF ARTS

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PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. XVI JUNE, 1903 No. 2

JUL 8 1903

PROCEEDINGS OF THE SOCIETY OF ARTS.

FORTY-FIRST YEAR, 1902–1903.

THE 575th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Friday evening, January 23d, at 8 o'clock, Professor Niles presiding. Eighty-five persons were present.

After the minutes of the previous meeting had been read and approved, Mr. F. H. Newell, Chief Engineer, United States Geological Survey, addressed the Society on "The Reclamation of the Arid Public Lands." The lecture was fully illustrated with lantern slides.

A vote of thanks was tendered the speaker and the meeting adjourned.

The 576th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, Thursday evening, February 12th, at 8 o'clock, Mr. James P. Munroe in the chair. Four hundred and fifty persons were present.

After the minutes of the previous meeting had been read and approved, Mr. George Kennan addressed the Society on "Martinique and Mt. Pelée."

A vote of thanks was tendered the speaker and the meeting adjourned.

The 577th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, February 26th, at 8 o'clock, Professor Cross in the chair. One hundred and twenty persons were present.

After the minutes of the previous meeting had been read and approved, Mr. George W. Miles, analytical and consulting chemist, was elected to Associate Membership in the Society.

The address of the evening was by Professor Louis Derr, who exhibited some new apparatus for illustrating certain electro-magnetic phenomena.

A vote of thanks was tendered the speaker and the meeting adjourned.

The 578th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 12th, at 8 o'clock, Mr. Peabody, of the Corporation, in the chair. Eighty-five persons were present.

After the minutes of the previous meeting had been read and approved, Mr. J. Knox Taylor, Supervising Architect, Treasury Department, addressed the Society on "Government Architecture."

A vote of thanks was tendered the speaker and the meeting adjourned.

The 579th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 26th, at 8 o'clock, Professor Talbot in the chair. Seventy-five persons were present.

After the minutes of the previous meeting were read and approved, Mr. H. J. W. Fay was elected to Associate Membership in the Society.

Mr. George W. Fuller then addressed the Society on "The Composition of Sewage with Relation to Problems of Disposal." The paper will be printed in full in the next number of the TECHNOLOGY QUARTERLY.

After the subject of the paper had been discussed by Professor Talbot, Professor Kinnicutt, and Professor Sedgwick, a vote of thanks was tendered the speaker and the meeting adjourned.

The 580th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 9th, at 8 o'clock, Mr. Munroe, of the Corporation, in the chair. One hundred and thirty-five persons were present.

After the minutes of the previous meeting had been read and approved, Mr. R. H. Dana addressed the Society on "The Charles River Dam." A number of lantern slides illustrating the subject were shown.

After a brief discussion, a vote of thanks was tendered the speaker and the meeting adjourned.

JAMES F. NORRIS, *Secretary.*

THE FIGURE OF THE EARTH FROM PENDULUM OBSERVATIONS MADE IN GREENLAND IN 1896 AND IN SUMATRA IN 1901 BY EXPEDITIONS FROM THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

By G. L. HOSMER.

Ever since Richer, in 1672, observed the variation of gravity with the latitude, the pendulum has been recognized by geodesists as a valuable instrument for determining the figure of the earth. The recent improvements of the so-called "invariable pendulum" make this instrument more important than ever before as a means of solving this problem.

In 1743, Clairaut published his theorem for finding the flattening of the poles from the value of gravity at the equator and at the poles. His formula is:

$$\frac{a-b}{a} = \frac{5}{2} \cdot \frac{c}{g_e} - \frac{g_p - g_e}{g_e} \quad (1)$$

where a and b are the major and minor semi-axes of the meridian ellipse; c is the centrifugal force at equator; g_p and g_e are the accelerations due to gravity at poles and equator respectively.

It is not practicable to get the value of gravity at the pole directly, but, since the law of variation is known, we may reduce observations at any latitude to the corresponding values at the pole. The formula for this variation is:

$$g_o = g_e \left(1 + \frac{g_e - g_p}{g_e} \sin^2 \phi_o\right) \quad (2)$$

in which g_o is the value of gravity in latitude ϕ_o.

From this formula it will be seen that determinations of gravity at two different stations will give a value of $\frac{a-b}{a}$, or the polar compression. If many observations are taken, the most probable values

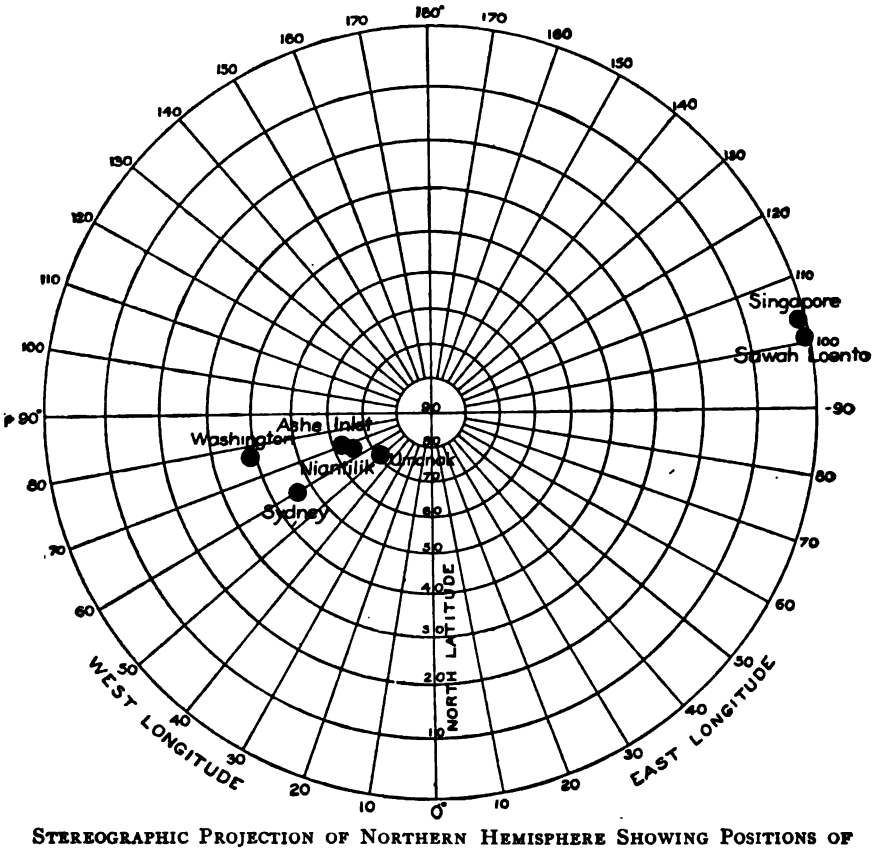
of g_1 and g_2 may be determined by the method of least squares and the value of $\frac{a-b}{a}$ may be found from these.

In this article we propose to derive a value for the polar compression depending upon observations for the force of gravity at the stations shown in the following table:

Station.	Observer.	Expedition.
Umanak, Greenland.	G. R. Putnam.	Boston party of sixth Peary expedition to Greenland, 1896, in charge of Prof. A. E. Burton.
Niantilik, Cumberland Sound.	G. R. Putnam.	Boston party of sixth Peary expedition to Greenland, 1896, in charge of Prof. A. E. Burton.
Ashe Inlet, Hudson Strait.	G. R. Putnam.	Boston party of sixth Peary expedition to Greenland, 1896, in charge of Prof. A. E. Burton.
Sydney, Cape Breton.	G. R. Putnam.	Boston party of sixth Peary expedition to Greenland, 1896, in charge of Prof. A. E. Burton.
Washington, D. C.	G. R. Putnam. G. L. Hosmer.	Reference station.
Singapore, Straits Settlements.	G. L. Hosmer.	Mass. Institute of Technology eclipse expedition to Sumatra, 1901, in charge of Prof. A. E. Burton
Sawah Loento, Sumatra.	G. L. Hosmer.	Mass. Institute of Technology eclipse expedition to Sumatra, 1901, in charge of Prof. A. E. Burton.

An inspection of the figure will show that these stations lie approximately along the same meridian. The measures of g were made with the half-second invariable pendulums belonging to the United States Coast and Geodetic Survey. This instrument gives the relative force of gravity at the points observed.

The values of g for the seven stations are shown in the following table. These values are based on the assumption that g at Washington is 980.102.



STEREOGRAPHIC PROJECTION OF NORTHERN HEMISPHERE SHOWING POSITIONS OF PENDULUM STATIONS.

STATION.	g REDUCED TO SEA-LEVEL.[1]	LATITUDE.	LONGITUDE.
Umanak.	982.595	+ 70° 40′ 29″	+ 52° 08′ 21″
Niantilik.	982.276	+ 64° 53′ 30″	+ 66° 19′ 32″
Ashe Inlet	982.111	+ 62° 32′ 48″	+ 70° 35′ 20″
Sydney.	980.723	+ 46° 08′ 32″	+ 60° 11′ 47″
Washington.	980.102	+ 38° 53′ 13″	+ 77° 00′ 32″
Singapore.	978.049	+ 01° 16′ 44″	— 103° 50′ 13″
Sawah Loento.	978.058	— 00° 41′ 40″	— 100° 46′ 40″

[1] For reports of these observations by the observers see Vol. X, p. 59, and Vol. XV, p. 35, of the TECHNOLOGY QUARTERLY and the Coast and Geodetic Survey Report for 1897, p. 299.

If we substitute in equation (2) for g_o the observed values, we obtain the following observation equations:

$$\begin{aligned}
982.595 - g_e - .890485\,(g_e - g_p) &= 0.\\
982.276 - g_e - .819943\,(g_e - g_p) &= 0.\\
982.111 - g_e - .787455\,(g_e - g_p) &= 0.\\
980.723 - g_e - .519930\,(g_e - g_p) &= 0.\\
980.102 - g_e - .394115\,(g_e - g_p) &= 0.\\
978.049 - g_e - .000498\,(g_e - g_p) &= 0.\\
978.058 - g_e - .000147\,(g_e - g_p) &= 0
\end{aligned}$$

$$\text{Assume } g_e = 978 + k$$

then the equations become

$$\begin{aligned}
4.595 - k - .890485\,(g_e - g_p) &= 0.\\
4.276 - k - .819943\,(g_e - g_p) &= 0.\\
4.111 - k - .787455\,(g_e - g_p) &= 0.\\
2.723 - k - .519930\,(g_e - g_p) &= 0.\\
2.102 - k - .394115\,(g_e - g_p) &= 0.\\
.049 - k - .000498\,(g_e - g_p) &= 0.\\
.058 - k - .000147\,(g_e - g_p) &= 0.
\end{aligned}$$

The normal equations are

$$\begin{aligned}
17.914 - 7k - 3.41257\,(g_e - g_p) &= 0.\\
13.07932 - 3.41257k - 2.51101\,(g_e - g_p) &= 0.
\end{aligned}$$

Hence $k = .0586$, $g_e = 978.059$ and $g_e - g_p = 5.1292$.
These values substituted in Clairaut's formula (equation 1) give:

$$\frac{a-b}{a} = \frac{5}{2}\cdot\frac{1}{288.41} - \frac{5.1292}{978.059} = \frac{1}{292.06}.$$

This value agrees closely with that given by Clarke in his work on geodesy, namely $\frac{1}{292.2}$. That a value derived from only seven observations should agree with one derived from a large number must be regarded as accidental, since the deviation of gravity at any station from the normal value may be considerable. The result indicates, however, that a few observations well distributed and all made with the same instrument, giving the relative force of gravity, will give a fair approximation to the true value. .

A STUDY OF THE GEOLOGY OF THE CHARLES RIVER ESTUARY AND BOSTON HARBOR, WITH SPECIAL REFERENCE TO THE BUILDING OF THE PROPOSED DAM ACROSS THE TIDAL PORTION OF THE RIVER.[1]

By W. O. CROSBY.

Introduction.

The investigation was intended to cover the geological history of the present harbor and its channels, including the estuary of the Charles, in order to learn how far these channels had their origin in tidal scour, and how far the reported conclusions of forty years ago regarding the origin and preservation of the channels are in accord with the teachings of modern geology.

It was also desired that all recorded borings in the vicinity of the site of the proposed dam should be studied from the geological point of view, in order to learn the character of the ground on which the dam, with its heavy masonry locks and sluices, would have to be built.

The Bed Rock.

The geological data having a bearing upon the problems presented by the proposed dam across the tidal portion of the Charles River are chiefly those relating to the glacial and postglacial periods in the history of the river. The underlying bed rock, largely of a slaty character, is in general, and especially for points near the modern river, so deeply buried beneath the glacial and later deposits as to be without appreciable direct influence in determining surface features and conditions. Under the general processes of glacial and preglacial erosion, however,

[1] This study, printed with permission of the Charles River Dam Committee, was made in order to answer certain questions propounded by J. R. Freeman, Engineer to the Committee, with special reference to the probable effect of the proposed dam near Craigie Bridge upon the shoaling of the harbor, and also in order to learn the character of the deep substrata at the proposed dam site in relation to furnishing an impervious and unyielding foundation for the dam, the locks, and the sluices

the character and structure of the bed rock have undoubtedly determined in a large degree the contours and trend of the bed-rock valley; but these are reflected in the surface topography only in a very broad and general fashion, and chiefly indirectly, determining the accumulation or massing of the glacial drift or bowlder clay in which the relief features of this part of the valley are now mainly expressed. It appears, therefore, that, notwithstanding its unobtrusive character, the bed rock is still a factor in this problem, and the natural starting-point of the investigation.

Character and Structure of the Bed Rock.

Many borings and excavations, supplemented by an occasional outcrop toward the head of the estuary, suffice to show that the concealed bed-rock floor of this part of the Charles River valley is mainly slate, of similar character to that so well exposed in the Somerville ledges and quarries, with probably, as in Somerville, an occasional dike of diabase (trap).

The general geologic structure of this district is comparatively simple. The main features, beginning on the south, are:

First. — A broad band of conglomerate, trending east-west through Newton, Brookline, Roxbury, and Dorchester to the harbor at Savin Hill. The structure of this belt of conglomerate is anticlinal, the beds dipping northward on the north side and southward on the south side, and passing in both directions beneath the overlying slate formation, which once arched completely over and concealed the conglomerate. Not only has erosion cut through the slate and deeply into the conglomerate, but to the westward, in Newton and Needham, it has also cut entirely through the conglomerate, exposing the ancient volcanic rocks — melaphyr and felsite — which here form the floor of the Boston basin. As it approaches the sea this broad arch of conglomerate narrows rapidly, the axis subsiding in this direction; but it probably extends at least as far east as Thompson's Island before it is completely covered by the slate. This anticlinal belt of conglomerate lies about midway between the northern and southern borders of the Boston basin — the northern highlands (culminating in Arlington Heights) and the Blue Hills, — and is at once the central and dominant arch or structural feature of the basin, determining, by its superior resistance to erosion as compared with the softer bordering slates, a topographic division of

the basin into two broad longitudinal valleys — the Charles and the Neponset.

Second. — Each of these main valleys is divided longitudinally by a subordinate belt of conglomerate and volcanic rock. That on the north, in which alone we are now interested, extends through Newton and Brighton, south of the Boston & Albany Railroad, but seems to die out in Brookline before reaching the Back Bay district of Boston, the belt of slate separating it from the main central belt of conglomerate widening rapidly eastward from the vicinity of Chestnut Hill Reservoir.

Third. — In the hills north of the Charles River, in Watertown, another, but very subordinate, anticlinal ridge of conglomerate rises through the slate. But with this exception, the entire area between the conglomerate of the Newton and Brighton ridge and the granitic rocks of the northern highlands, expanding eastward to embrace Belmont, Cambridge and Somerville, is underlain, so far as known, by slate, which, in the longitude of Boston proper, is probably continuous from Arlington Heights to the northern boundary of Dorchester and the southern shores of South Bay and Old Harbor.

Fourth. — Below Riverside the course of the Charles River is wholly confined to the southern part of the broad, northern slate area, where the structure is clearly synclinal, the topographic valley coinciding with a geologic valley. The trend of this slate syncline, conforming with the Newton and Brighton anticline, is first to the north-northeast, parallel with the western border of the basin, nearly to Waltham, and then to the eastward, as far as Cambridgeport and the eastern end of the anticline, where, probably, it is deflected toward a southeasterly course in conformity with the ledges of Somerville and Governor's Island. Having once reached this trough of relatively soft rocks, the river has followed it to the sea, and continues to follow it, with some obvious meanders and digressions, in spite of the deep drift deposits which now encumber and obscure its bed-rock valley.

Topography of the Bed Rock.

The general conclusions to be noted under this head are mainly based upon, first, the actual outcrops of the bed rock; second, the drumlins or special accumulations of bowlder clay, which are usually either based upon ledges or indicate relatively elevated portions of the bed-rock surface, and embrace nearly all the bowlder clay of this area

not covered by modified (washed and stratified) drift; and, third, and especially, upon all the deep borings and excavations of which I have been able to obtain a definite record.

It may be noted not only that the distribution of the drumlins is in harmony with that of the rock outcrops, the two classes of facts co-operating to determine the outline of the bed-rock valleys; but also that the bed-rock contours, based chiefly, as stated, upon the borings, are yet in harmony with both the natural outcrops and the drumlins.

We thus discover not only that the bed-rock valley of the Charles River follows approximately the modern course of that stream below Riverside, and that both are in substantial harmony with the geologic structure; but also that it is joined, between Brighton and Cambridge, by a still deeper and broader valley from the northward, which is readily identified as a direct southward continuation of the valley of the Mystic River where it cuts through the northern highlands and enters the Boston basin.

The highland section of the valley of the Mystic is, in size, out of all proportion to the diminutive stream which now poses as its architect; and, as I have elsewhere shown,[1] it is highly probable that we have here the preglacial channel of the Merrimac River, which followed the general course of the Middlesex canal from the great bend at North Chelmsford to West Medford, whence, instead of bending abruptly to the eastward, as does the modern Mystic, it continued in the same general direction across Cambridge to its confluence with the Charles, this part of its course being approximately marked now by the basins of Spy and Fresh ponds, and being further attested by the deep boring near the outlet of Fresh Pond, which reached bed rock at a depth of 148 feet, or about 130 feet below mean sea level.

The Charles thus appears as a preglacial western tributary of the preglacial Merrimac; and the course of the united streams, or of the Merrimac after receiving the waters of the Charles, was clearly not that of the modern Charles around the north end of Boston, but directly across the Back Bay and the South End districts of Boston (Boston Neck and Dorchester Neck) to Old Harbor.

It is extremely probable, as will appear more clearly later, that the slate ledges of Somerville are continued as more or less distinct

[1] TECHNOLOGY QUARTERLY, Vol. XII, p. 302.

ridges underlying Charlestown and the north end of Boston. These ridges are doubtless more or less irregular and discontinuous; but there seems to be no reason to doubt that they should be regarded as an effectual bar to the view that the preglacial drainage of the Charles River valley followed the course of the modern river below Harvard Bridge.

On the other hand, the far more direct southern course is free and unobstructed to a depth of 200 feet or more. The southern border of this valley is quite well defined by the outcropping ledges in Brighton, Roxbury, and Dorchester, and the northern border is also indicated by less prominent ledges in South Boston. Reviewing the borings, we find that beneath Cambridgeport the bed rock is from 110 to at least 150 feet below sea level, rising toward the north; across the Back Bay and South End districts of Boston, several borings have reached the bed rock at depths of 140 to 170, and even 200 feet; and a boring near the northern shore of the Calf Pasture in Dorchester, and presumably on the southern slope of the valley, reached bed rock at a depth of 166 feet; while at the pumping station of the main drainage system, at Old Harbor Point, bed rock was reached at a depth of 214 feet, or 204 feet below low tide. It is apparent that from West Medford the preglacial Merrimac held its southward course across the Boston basin until it was joined by the Charles near the east end of the Newton and Brighton anticlinal band of the harder rocks; and that from this point the course was more southeasterly, but still crossing the strike of the slate beds, until it met the north side of the great Brookline and Savin Hill arch of conglomerate, which deflected it to the eastward, the seaward course of the buried channel being probably to the north of Thompson's and Spectacle islands, and thence seaward *via* Presidents Roads and Broad Sound.[1]

Continuing the general view of the bed-rock topography and recalling that the normal bed rock for the entire district north of the highlands is slate similar to that of the Somerville ledges, we may note: first, that the prevailing strike of the slate, so far as determined, varies from approximately east-west near the Charles River to about northwest-southeast in the vicinity of the Mystic; and, second, that the slate, more or less steeply inclined at most points, naturally

[1] This problem of the preglacial course of the Charles River has been ably discussed by Mr. F. G. Clapp, TECHNOLOGY QUARTERLY, Vol. XIV, p. 198.

tends to form ridges trending with the strike, with, of course, intervening valleys, which must in general slope seaward. This is confirmed by all the outcrops and all the borings which have reached solid bed rock. It may also be assumed that all parts of the bed-rock surface would, if bare and elevated above sea level, exhibit free drainage; in other words, that there are in this district no true rock basins.

One of the longest and most pronounced of the bed-rock ridges is indicated by the drumlins of College and Winter hills and the ledges on which they rest, Convent Hill (recently removed), Bunker and Breed's hills in Charlestown, Man-of-War Shoal (summit of a submerged drumlin), the low drumlin culminating in Maverick Square, East Boston, and the more prominent East Division drumlin, Bird Island flats (another submerged drumlin), Governor's Island drumlin and ledge, and the flats extending a mile beyond. It is a fair assumption that a ridge of this length is composite, consisting of overlapping and more or less distinct members; and probably the lowest point is between Charlestown and East Boston, this *col* descending, possibly, 100 feet below low tide and marking the head of a valley descending to the south, between Boston and East Boston. Whether simple or complex, this ridge is clearly the southern slope or wall of a deep main valley, following the present course of the Mystic below West Medford, and the product especially of the drainage of the Malden and Melrose valley. The deep borings on the north side of Charlestown, reaching depths of — 100 to — 120 feet,[1] are doubtless in this valley, but south of its axis; while the Chelsea Ferry boring, reaching the ledge at about — 65, is well up on the north slope and this is confirmed by the Government Hill drumlin; and that the true course of the valley is directly east from the mouth of the Mystic, across East Boston in the vicinity of Central Square, south of Eagle Hill, is indicated by the geological structure, and suggested by a boring which failed to reach bed rock at a depth of — 100 feet on the flats between the First Division drumlin and the small drumlin of Wood Island Park. This course continued leads to a confluence with the Merrimac-Charles valley between Deer Island and Long Island.

[1] From this point on, depths and elevations are referred to Boston base or approximate low tide.

The ledge later to be described as underlying the Warren Bridge and Copp's Hill may apparently be regarded as a southern branch of the ridge just described, or, perhaps better, as a minor ridge between this and a second main ridge including, besides the ledges of Clarendon and Powder House hills, the drumlins of Spring, Central, Prospect and Asylum hills in Somerville, East Cambridge Hill, Beacon and Fort hills in Boston and the Burnham Channel ledge. The East Somerville drumlin tends to connect these two linear series of hills; and, while to the northwest of this point the ancient drainage may have been tributary, laterally through the first ridge, to the valley of Malden River, to the southeastward it was quite certainly longitudinal, passing beneath the present bed of the Charles River between the Lowell and Warren bridges, as will be more fully shown in a later section, and thence eastward between Beacon and Copp's hills and north of Fort Hill. Some idea of the depth of this part of the valley is afforded by the fact that bed rock was not reached at —115 feet at the corner of State and Broad streets, and only at a depth of —135 feet close on the northeast side of Fort Hill. Farther east, confluence with the minor valley heading in the neighborhood of the Man-of-War Shoal appears probable, and the course is indicated by a boring with a record of —118 feet and no rock at Pier 4, South Boston. Beyond this the course is open to doubt, but is probably north of the Burnham Channel ledge and south of Castle Island to a confluence with the Merrimac-Charles valley between Castle and Thompson's islands.

The drumlins of North Cambridge suggest, in connection with the Spring Hill and Winter Hill drumlins and their associate ledges in Somerville, a transverse ridge or water parting; and from the southwestern end of this ridge a third northwest-southeast ridge extends at least as far as the city hall, the slate bed rock on this line having been well exposed in sewer excavations in the yard of Harvard College, and almost continuously southward to the river. Between this area of a relatively high bed-rock surface and the ledges and drumlins of Somerville is apparently a broad valley, the drainage of which, as indicated by the low level reached by the bed-rock surface in several borings in the lower part of Cambridgeport, probably escaped to the southward to become immediately tributary to the Merrimac-Charles valley.

Only one other bed-rock ridge remains to be mentioned. This

embraces the drumlins and ledges of South Boston, including the Half-tide Rock; and with greatly diminished height it appears to be continued westward under South Bay and the South End into the heart of the Back Bay district. The borings indicate that west of South Bay the elevation of the crest of the ridge varies between —60 and —80 feet to its abrupt termination.

North of this deeply buried western half of the South Boston ridge, between it and the high Beacon Hill section of the Somerville and Boston ridge, is a broad, deep valley, the axis of which is at least 160, and probably 200, feet or more below the Boston base. The anomalous feature of this valley is that, while it appears to merge broadly with the Merrimac-Charles valley on the west, it is, for the lower levels, closed to the eastward. It appears thus as a short, broad, deep, *retrograde* tributary of the main drainage channel of the region.

In seeking an explanation of this depression, we may profitably note the fact that some of the borings reporting bed rock in the section of Boston south and east of Beacon Hill have clearly not reached any of the hard and thoroughly solid rocks (slate, conglomerate, trap, etc.) such as make up the whole of the bed-rock surface wherever it is exposed in ledges and shallow excavations; but instead the drill has passed from the glacial drift to imperfectly consolidated sands, clays, marls, etc., in part of colors unknown to the drift, and probably representing Tertiary strata underlying the drift and filling deep depressions or valleys in the harder formations or true bed rocks of the region. The artesian well of N. Ward & Co., on Spectacle Island, 560 feet deep, passed through at least 360 feet of unconsolidated material, only part of which could be regarded as glacial drift; and the deep well at the corner of High and Purchase streets in Boston, reported as reaching the bottom of the drift at about 100 feet, is in soft materials comparable with the Tertiary deposits of Martha's Vineyard and Long Island, to a depth of at least 500 feet. Following up this idea, it is a natural suggestion that during the strong elevation of the land at the close of Cretaceous time the Merrimac-Charles River, then flowing directly eastward south of Beacon Hill and Fort Point Channel, cut a deep valley in the ancient bed rocks of the region; and then during the Tertiary subsidence the lower portion at least of this valley was filled by Tertiary strata, and thus virtually obliterated; and the stream, during the succeeding ele-

vation, chose a new course across the horizontal Tertiary plain, and parallel with the great conglomerate anticline, where during the Pleistocene (early glacial) elevation it again trenched the older bed rocks, this channel being in turn obliterated by the deposits of the glacial period; and the river, in obedience to merely fortuitous or accidental causes, adopted its present circuitous course around the north end of Boston. It would thus appear that the channel was originally directly across the city proper (Cretaceous time), and that in the later history of the river it was diverted first to the south (Tertiary and Pleistocene times) and then to the north (postglacial time).

According to this view, the anomalous retrograde bed-rock valley south of Beacon Hill is the original channel partially re-excavated during the early Pleistocene elevation of the land.

Normal Profile of the Bed-Rock Channel, and Its Relations to the Early Glacial History of the Region.

For one important feature of the bed-rock topography we are not directly dependent upon either surface observations or borings, since it is a universal feature of the major valleys of the glaciated zone, and, in a general way at least, may safely be inferred where the data fall short of a complete demonstration. The feature referred to is an inner gorge, trenching the floor of the main valley and extending into the principal tributary valleys. This gorge is in this region rather seldom indicated in the surface topography, being almost universally filled by drift deposits, and thus obliterated as a topographic feature. It has been fully demonstrated for the valley of the Nashua River by the numerous deep borings made by the Metropolitan Water Board in the vicinity of Clinton, revealing a narrow gorge some 200 feet deep, dividing the bed-rock floor of this broad valley.[1] It is demonstrated also for the valley of the Merrimac by the deep borings of the Lowell water works, between Lowell and North Chelmsford, the gorge in this instance being about 100 feet deep, and its bottom at or below sea level; and also by the deep basin of the lower Mystic Lake, the water in which has a depth of 75 feet, and probably overlies a very considerable depth of drift.[2] Similar facts have been observed for many other streams; and the gorges of the larger rivers may be traced seaward for many miles,

[1] Technology Quarterly, Vol. XII, p. 294.

[2] Technology Quarterly, Vol. XII, p. 300.

the gorge or submerged fiord of the Hudson having still an unfilled depth below sea bottom, as determined by soundings, of over 2,800 feet, 80 miles east of Sandy Hook.

We find the simple and sufficient, and apparently the only possible, explanation of these phenomena in a strong elevation of the land at the beginning of the great ice age; this elevation, which amounted in this latitude to at least 3,000 feet, being regarded by many glacialists as the chief cause of the continental glaciation. This continental uplift must have proved a great stimulus to the drainage, especially near the continental border; and the streams, as their fall and erosive power increased, must in general have ceased meandering and thus slowly widening their valleys, and begun to cut rapidly downward toward a new base level. Thus were developed, before the land was finally covered by the great ice sheet, a system of deep, U-shaped gorges, trenching the floors of the relatively broad and shallow preglacial valleys.

In this vicinity the borings are insufficient to define the gorges of the Charles and Merrimac valleys; and it is at least among the possibilities that no borings have been located on the deepest lines or axes of the broad valleys. Of the existence of a deep inner valley there can, however, be no question. A well-defined lateral gorge is clearly indicated by the borings in the valley of Stony Brook, where it cuts through the Roxbury highlands. To this inner valley or gorge and its tributaries the floor of the preglacial valley stands in the relation of a terrace; but the borings appear inadequate at most points to determine satisfactorily the normal elevation of this terrace. In the Back Bay and South End districts, however, or just where the surface features count for the least in locating the gorge and determining the breadth and elevation of the bed-rock terrace, the borings do help us out to some extent, showing the general floor of the preglacial valley to be at least 60 feet below mean sea level.

Bed-Rock Details for the Charles River Below Harvard Bridge.

The modern course of the Charles below the Harvard Bridge is not only unnaturally circuitous, but the depths of the bed-rock surfaces are in part much less than at points farther up stream. The evidence may be briefly summarized here: —

The 39 borings on the line of the Harvard Bridge to depths ranging from —31.4 to —77.7 feet failed in every instance to reach bed rock, the entire series ending in blue clay. The deepest boring, —77.7 feet, is 100 feet from the Boston end of the bridge.

The borings for the new West Boston Bridge, 64 in number, on three different lines, and varying in depth from —36.9 feet to —73.5 feet, also failed in every instance to reach bed rock. Three borings, —46.4, —46 and —51.6 feet, struck rock, marked on the profiles "stone, probably bowlder," and this interpretation is probably correct. It may be added, however, that all of these borings ended in bowlder clay, indicating that the bed rock is less deep than at the Harvard Bridge.

No borings are available for the Craigie Bridge, but for the first bridge of the Boston & Lowell Railroad, built in 1833, we have a full series. This bridge, which is now used for freight tracks of the Boston & Maine Railroad, crosses the river somewhat diagonally, at a mean distance of about 250 feet below the Craigie Bridge. The borings, numbering 133, in two lines, the southern line being most complete, range in depth from —12 to —45.4 feet; and with a very few exceptions they all end on or in bowlder clay, although apparently no serious attempt was made to penetrate the bowlder clay or hard pan. At the Boston end of the bridge several borings in each line reached slate bed rock at depths varying from 12 to 17 feet below low tide, the depth increasing westward.

No boring data for the other railroad bridges have come to light; but for the Warren Bridge we have a series of 10 borings, extending across the river; and with two exceptions they all reach bed rock, at depths ranging from —11.84 to —39.68 feet.

Of the 70 borings made for the new Charlestown Bridge, on three different lines and to depths ranging from +4.3 feet to —58.3 feet, the deeper borings being mainly toward the Boston side of the river, only one is reported as reaching ledge, and this at a depth of only —11 feet in Charlestown. Another boring, 175 feet nearer City Square, is marked as ending on a bowlder at a depth of —5.7 feet, and it appears highly probable that this interpretation should be applied in both cases. This appears the more necessary, since, with the exception of two borings near the Boston end of the bridge which end in blue clay, they all end in bowlder clay.

Of 55 borings made for the new dry dock at the Charlestown

Navy Yard, in an area 1,300 by 700 feet, and reaching depths ranging from —33 to —104.4 feet, nine reached slate bed rock at depths varying from —39 to —98, and penetrated it 0 to 14.4 feet. A comparison of these bed-rock determinations shows that they partially outline a valley deepening in a northeasterly direction.

These several series of borings clearly indicate a bed-rock ridge crossing the river, the crest of the ridge being on or near the line of the Warren Bridge. Apparently the only alternative is to assume that, in the case of each of the Warren Bridge borings reported as ending on rock, the rock was a bowlder, and not ledge. But, even then, such frequency of bowlders large enough to be mistaken for ledge would suggest the close proximity of the ledge.

In East Cambridge and Charlestown bed-rock determinations, besides those already mentioned, are few, and none are very shallow. Two or more wells of J. P. Squire & Son on Gore Street, East Cambridge, reached bed rock at about —45 feet; a well of the Charlestown Gas Company at Thompson Square encountered bed rock at the same depth; and it was found at a depth of —59 feet in the well of G. G. Fox, Edgeworth and Vine streets, Charlestown. Although not very shallow, these borings are clearly not deep enough to suggest their location in or near the preglacial channel of the Charles; and it may quite safely be assumed that the drumlins of East Cambridge, Asylum Hill, Breed's Hill, and Bunker Hill rest on still more elevated portions of the bed-rock surface.

On the Boston side of the river borings and bed-rock determinations are much more numerous, and sufficient to develop, at least approximately, the form of the bed-rock surface. Starting from the Boston end of the old Boston & Lowell Railroad Bridge, where, as already noted, slate bed rock was reached at depths ranging from —12 to —17 feet, we find that the bed-rock surface rises southward, toward the low ridge or drumlin crossed by Leverett and Chambers streets, and that it formerly reached the level of low tide at the corner of Brighton and Lowell streets.

The borings made for the Charles River embankment, extending from Leverett Street and the Craigie Bridge to Cambridge Street and the West Boston Bridge, along the front of the wall, and to the number of 50, ranging in depth from —0.8 to —63 feet, discovered bed rock at 32 points, between 200 and 950 feet south of Craigie Bridge, at depths varying from —0.8 to —44.6 feet. These bed-

rock determinations are so grouped as to indicate a rather flat-topped ridge, from 1 to 8 feet below low tide, with fairly steep lateral slopes; clearly a northwestward continuation of the ridge on which the Chambers Street drumlin is built, and probably continuous under the river with the bed-rock elevation bearing the East Cambridge drumlin.

On Charles Street, about 200 feet east of the embankment line of borings, we have a nearly parallel profile in the 22 borings, 0 to — 33 feet in depth, made for the new sewer between Leverett and Cambridge streets. Of this series, 10 borings reached bed rock at depths of 0 to — 13 feet within a distance of 800 feet south from Leverett Street; and continuing through Leverett and Brighton streets to Lowell Street we find 7 borings, all of which reach bed rock at depths from + 8 to — 10 feet. A comparison of the profiles shows the average elevation of the bed rock to be increasing eastward, although the ridge is divided on Charles Street by a valley at least 15 feet deep.

That this ridge continues to the eastward we have abundant evidence in the fact that the sewers have also encountered ledge (slate) on Poplar Street and Kennard Avenue, and that the following houses stand on slate ledge, at elevations ranging from + 15 to at least + 25: Nos. 33 and 67 Poplar Street, corner of Poplar and Spring streets, corner of Milton and Spring streets, and corner of Poplar Street and Kennard Avenue. The general course of this ridge is southeasterly, with the axis of the drumlin, as shown by bed-rock elevations of — 15 feet in the wells of Fobes, Hayward & Co., on Chardon Street, and Graves & Sons, Bowker Street; — 50 feet at Marston's Restaurant, on Hanover Street; — 28 feet at Pemberton Building, Pemberton Square; and — 15 feet, corner of Washington and Court streets. The narrowness of the ridge is proved by a bed-rock elevation of — 15 feet in the artesian well of the Massachusetts General Hospital, near the corner of Allen and Blossom streets.

Following the profile of the Charles Street borings southward, around the base of the main drumlin of Beacon Hill, we have 14 borings, ranging from about + 1 to — 14 feet in depth. Of these, 4 reached the slate bed rock in the vicinity of Pinckney Street, on the axis of the drumlin, at depths near the low-tide level (+ 1 to — 2), and two others, between Mt. Vernon and Chestnut streets, at depths of — 10 and — 14 feet, approximately.

The broad valley between Beacon Hill and its dependent drumlins

and the relatively small but well-defined drumlin of Copp's Hill corresponds to a bed-rock valley. Of this we have abundant evidence. Thus, of the 15 borings for the new sewer, on Causeway Street between Lowell and Prince streets, reaching depths of +8 to −36 feet, only those at the intersections of Charlestown and Prince streets, and possibly only the latter, reached bed rock, at elevations of +1 to +8 feet. All the other borings of this series terminated in blue clay or sand, not one of them even reaching the bowlder clay, which presumably covers the bed rock in the valleys, as well as on the ridges, though less thickly. In close proximity to the Prince Street boring is the deep artesian well of the Boston Gas Company, in which slate bed rock was reached at −35 feet. The bed-rock elevation proved by the borings is probably an eastward extension of the bed-rock ridge disclosed by the Warren Bridge borings, and it may be assumed to continue as the axis or foundation of Copp's Hill. Between Copp's Hill and Beacon Hill we have the following additional bed-rock elevations, afforded by artesian wells and borings, and proving the existence of a bed-rock valley at least 75 feet deep below Boston base: Moxie Nerve Food Company, Haverhill Street, −53 feet; Schrafft & Sons, Portland Street, −65 feet; Tufts old factory, Portland Street, −49 and −74 feet; Eastern Cold Storage Company, 28–44 North Street, −104 feet; Boston subway borings, between Causeway and Hanover streets, −5 to −40 feet, in clay and no rock.

The Bowlder Clay and Drumlins.

The bowlder clay, or hard pan, known by geologists also as the till or ground moraine, is the unmodified (unwashed and unstratified) portion of the glacial drift, or that part of the drift deposited on the final melting of the ice sheet without being exposed to the effective sorting or modifying action of water. It rests at most points directly upon the bed rock, and in this region at least is found chiefly on the higher parts of the bed-rock surface, where it is very largely massed in the form of rounded hills or drumlins. The practical exclusion of the bowlder clay from the deeper valleys is a fact of great significance and interest, indicating that the ice continued to move along these lines after it had become stagnant on the uplands, and suggesting comparison with a river, the chief deposits of which are not on its bed but on its flood plain.

As regards its relations to the subterranean movement of water and the stability of foundations built upon it, the bowlder clay, having been compacted by the tremendous and long-continued pressure of the ice sheet, is comparable with the underlying bed rock; and in this connection it is interesting to note the concentration of bowlder clay in the vicinity of, and below the site of, the proposed dam, as indicated by the drumlins and numerous borings. The main facts are clearly and instructively exhibited in a direct comparison of the borings.

Thus, beginning on the southwest, or over the main bed-rock valley, we find that none of the Harvard Bridge borings encountered the bowlder clay; although the minimum elevation reached by the borings is —77.7 feet, they all ended in blue clay, which overlies the bowlder clay. Of the numerous borings for the West Boston Bridge, all reached bowlder clay at elevations ranging from —29.4 feet at the Boston end of the bridge, where the slope of the Beacon Hill drumlin passes beneath the river, to —66.1 feet at a point 300 feet farther west. From the axis of this bowlder clay valley, which is indicated on each of the three lines of borings, and slopes northward from —57.5 feet on the south line of borings to —66.1 feet on the north line, or approximately 10 feet in 100, the surface of the bowlder clay rises westward to elevations between —40 and —30 in about 300 feet, beyond which it falls off to about —50 in the next 400 to 500 feet, and then continues with a slightly undulating surface but no decided or general slopes for fully 1,000 feet, or to the Cambridge shore, where the elevations on the different lines are, from south to north, —55.35, —50.5 and —49.3 feet. This approximately plane upper surface of the bowlder clay is undoubtedly very characteristic of the interdrumlin areas, and probably indicative of a similar flat bed-rock surface below a moderate thickness of bowlder clay.

The Charles River embankment borings, although extending across the axis of the northern spur or member of the Beacon Hill drumlin, and ranging in depth to a maximum of —63 feet (midway between the West Boston and Craigie bridges), have all failed to reach the bowlder clay, showing apparently that the valley in the bowlder clay developed by the West Boston Bridge borings continues under the eastern margin of the river at least as far as Craigie Bridge, and probably continues to deepen in that direction, since it is improbable that the embankment borings are near the axis of this trough.

The Charles Street sewer borings, following more closely the base of the drumlin, have found the bowlder clay at or near the surface at nearly all points between Beacon and Cambridge streets, although it is difficult here to distinguish original deposit from artificial filling; but between Cambridge and Leverett streets, where most of the borings not ending on the high level bed rock attained depths of — 25 to — 33 feet, none have encountered typical bowlder clay, developing chiefly clay of a more or less sandy character.

The numerous borings of the original Boston & Lowell Railroad Bridge reached the bowlder clay in most cases, and at depths averaging much less than for the West Boston Bridge borings, although again we note a surprising uniformity of depth for the main part of the profile. For the first 300 feet from the East Cambridge shore the borings were too shallow (— 17 to — 23 feet) to reach the bowlder clay; but for the next 250 feet it is developed at depths ranging from — 23 to — 33 feet. In the next 250 feet depths of — 40 to — 45 have ended in blue clay, marking the position of the deep channel in the bowlder clay with depths of the bowlder clay surface probably exceeding 70 feet, if the valley continues to deepen northward. This locates the bowlder clay channel near the middle of the river at this point; and east of the channel the bowlder clay shows again a striking uniformity of elevation, ranging only from — 31 feet to — 35, for fully 800 feet, or to the slate ledge on which the east end of the bridge rests.

On the line of the Warren Bridge two borings, 275 and 280 feet from Causeway Street, reported bowlder clay at depths of — 16.3 and — 27.6 feet, and 670 feet from Causeway Street at — 33.3 feet. These are clearly on the northwestern slope or toe of the Copp's Hill drumlin. At 918 feet from Causeway Street bowlder clay is wanting, and rock was reached at — 11.8 feet. The next boring, 1,118 feet from Causeway Street and 696 feet from Water Street in Charlestown, ends in gravel at — 16 feet, and the next, 576 feet from Water Street, in clay and stones (probably bowlder clay) at — 32.2 feet. Beyond this we have, at 490 feet from Water Street, rock at — 32.2 feet and no bowlder clay; and at 264 and 190 feet, respectively, from Water Street, rock at — 12 and — 15 feet, and no bowlder clay. These facts seem to prove the existence, between the Copp's Hill and Beacon Hill drumlins on one side and the Charlestown drumlins on the other, of a ledgy tract, essentially bare of drift,

as is so commonly observed between well-developed drumlins above sea level; and it appears improbable that the valley in the bowlder clay, traced from the West Boston to the Craigie Bridge, finds an outlet in this direction, but, if continued, it is more likely to turn to the eastward, between Beacon and Copp's hills. It is, however, quite unnecessary to regard this as an erosion or drainage channel, and if it is, its true slope or gradient may after all be to the south into the main valley.

The borings for the Charlestown Bridge, connecting still more closely with the stoss slope of Copp's Hill, all ended on or in bowlder clay, proving the elevation of its upper surface to range between + 13.8 feet in City Square, Charlestown, and — 53 feet under the main channel, about 500 feet from Causeway Street in Boston. The three separate lines of borings agree very closely, each revealing a simple bowlder clay valley, with a short, steep slope toward Boston, rising to the surface in Causeway Street, and a long, gentle but undulating slope toward Charlestown; and the comparison shows quite plainly that the axis of the valley descends eastward, or toward the harbor. This valley is evidently not deep enough to be regarded as a down-stream continuation of the valley noted in the profiles south of the Warren Bridge; and we cannot escape the conclusion that the Warren Bridge marks the true divide for the bowlder clay as well as for the bed rock. The probability that the southern bowlder clay channel or valley descends either to the south or to the east becomes a practical certainty; although it is perhaps most probable that it descends both ways from a divide in the vicinity of Craigie Bridge, which would again bring the contours of the bowlder clay into harmony with those of the bed rock.

The Navy Yard borings all penetrate the bowlder clay, and the elevations of the surface of this deposit show again a fair degree of uniformity, although the extremes are + 7 and — 63, — a range of 70 feet. Four-fifths of the determinations fall between — 10 and — 40 feet, and over half of them between — 15 and — 35 feet. The contours of the bowlder clay show no regard whatever for the bed-rock valley previously noted as sloping to the northeast; and over the deepest part of this valley the bowlder clay attains an extreme thickness of 85 (— 13 to — 98) feet. The bowlder clay contours run lowest to the south, evidently declining toward a bowlder clay valley between the Navy Yard and the Man-of-War Shoals

drumlin, which may fairly be regarded as the down-stream continuation of the valley in the bowlder clay disclosed by the Charlestown Bridge borings; and it may be added that the depths are entirely favorable to that view. The farther extension of this valley, assuming it to be the product of stream erosion and a true drainage channel, may be either to the north, toward the deep, preglacial valley of the Malden River, or to the east, between Copp's Hill and the East Boston drumlins, the data in hand being insufficient for the determination of this point.

Under the harbor, on the lines of the East Boston tunnel borings, the surface of the bowlder clay has a fairly uniform elevation of —80 to —90 feet, averaging a little lower in the northern or North Ferry profiles than in the southern or South Ferry and State Street profiles. The flatness or approximately plane character of the surface of the bowlder clay is quite as marked here as under the Charles River, although the actual elevation is 20 to 50 feet less. That this great depth of the bowlder clay continues and increases around the south and west sides of Copp's Hill is shown by the failure of all the East Boston tunnel borings in the State Street section to get below the blue clay, and the fact that the artesian wells on North Street found the blue clay resting directly on the slate bed rock at a depth of 104 feet.

At many points the bowlder clay is separated by a few feet of bluish (unoxidized) sand and gravel, often more or less clayey, from the blue clay, giving a gradation from the bowlder clay into the blue clay, and showing that the former was exposed somewhat to the sorting action of water at the beginning of the deposition of the latter. A feature of the bowlder clay of still more special interest is found in the interstratified beds of washed material, including gravel, sand and clay. This has been noted in some of the borings for the Charlestown Bridge; and in at least ten of the Navy Yard borings the bowlder clay is divided by one and in some cases two layers of sand, varying from 1 to 5 feet in thickness, and separated by 15 to 20 feet of bowlder clay. This intercalation of limited layers of washed material in the bowlder clay is not uncommon; but it is usually confined, as in this instance, to the lee slopes of drumlins, the Navy Yard borings being directly in the lee of the Bunker Hill drumlin; and this relation is very satisfactorily confirmed by the East Boston tunnel borings in the lee of Copp's Hill and the

subway borings in the lee of Beacon Hill. This principle would exclude washed material from the bowlder clay north of Beacon Hill; and this is precisely what, with unimportant exceptions, the several bridge profiles show. The exceptions are impervious blue clay, and no facts have come to light indicating that the bowlder clay in the vicinity of the site of the proposed dam falls below the normal as regards either firmness or impermeability.

Glacial Lake Shawmut.

During the final disappearance of the ice sheet, the ice lingered longer, as previously stated, in the valleys than on the uplands, and much longer in the basin of Boston Harbor and Massachusetts Bay than over the country to the westward, including the main part of the Boston basin. The eastward drainage was thus impounded, forming the glacial lake to which I have given the name of Shawmut, communicating on the southeast with glacial Lake Bouvé during the time when the latter discharged eastward into Cohasset Harbor. At its highest stage the surface of Lake Shawmut was about 70 feet above the present level of the sea, the elevation being marked by extensive delta plains of sand and gravel formed by the tributary glacial streams, the courses of which are now marked, in some cases, by winding ridges of gravel known as eskers. With the continued recession of the ice, successively lower outlets for the united waters of lakes Shawmut and Bouvé were opened, and we find, in consequence, eastward from the 70-foot plains, extensive delta plains at elevations of 40 and 20 feet, approximately, and extending in the south part of the Boston basin to the present shore of the harbor.

While these deposits of relatively coarse detritus, resulting from the washing of the bowlder clay or ground moraine as it was being set free by the melting of the ice, were forming in the shallow marginal portions of Lake Shawmut, adjacent to the northward-receding margin of the ice, the finer material (quartz flour and clay), once incorporated with the coarse in the composition of the bowlder clay, was being deposited in the deeper and more tranquil part of the lake, remote from the mouths of the glacial rivers. Thus was formed the important deposit known as the blue clay or glacial clay. It was laid down in regular horizontal layers, and probably completely filled the basin of Lake Shawmut up to the highest level now reached by the clay, which is about 5 to 10 feet above the present high-tide level.

The Blue Clay.

Under Boston Harbor and its tributary estuaries we find above the bowlder clay, or above the bed rock where the bowlder clay is wanting, in normal order the blue clay. This, as we have seen, is a true glacial clay, a deposit of impalpable detritus from the waters of the glacial lake (Lake Shawmut) which came into existence as the ice retreated from the area of Boston Harbor, the land being still much more elevated than at present. This body of fresh water, free from tidal currents, and frozen over during a large part of each year, presented, in its freshness and tranquillity, conditions exceptionally favorable for the deposition of quartz flour and clay. That the blue clay is not marine is proved by the entire absence of fossils, and the fact that similar clay is not being deposited in the harbor at the present time, except perhaps to a limited extent on the eel-grass flats. It is in the main a very tough, plastic clay, but containing, as do all glacial clays, a large portion of impalpably fine sand or quartz flour. There are, however, occasional thin streaks and layers of true sand, representing periods when there was more motion in the water.

The angular fragments and grains of rock, of all sizes up to bowlders several feet in diameter, scattered irregularly here and there through the clay, as so well shown by the East Boston tunnel, and most abundantly, as a rule, toward the bottom of the deposit, are a very characteristic and significant feature of the clay. This material could not have been borne in suspension by the same currents that deposited the clay, but it was undoubtedly dropped by floating ice — floe ice and icebergs. Another convincing proof of the glacial origin of the blue clay is found in the fact that in a number of the East Boston tunnel borings, on the west side of the harbor, and more or less in the lee of the Copp's Hill drumlin, the clay is divided, usually near the bottom, by a sheet of bowlder clay from 10 to 25 feet in thickness. Similar phenomena have been observed elsewhere, as in the lee of the Beacon Hill drumlin, and, as previously noted, in one of the Charlestown Bridge borings. Apparently, this means that when the deposition of the clay began in this part of the harbor the margin of the ice sheet was still near by, so that a slight readvance of the ice spread a layer of bowlder clay over a part of the blue clay; and when the ice again retreated, this intrusive sheet of bowlder clay was in its turn covered by a considerable thickness of the blue clay.

A more probable explanation, however, is found in the agency of floating ice, as for the disseminated glacial detritus.

The borings show that the clay beds reach an extreme elevation of about 5 feet above high tide, which accords well with observations made in the clay pits of Everett and West Cambridge; and it extends to a depth of 80 to 90 feet below low tide in many of the East Boston tunnel borings, and to still greater depths, down to nearly 200 feet below the same datum in artesian wells and borings located in the deeper bed-rock valleys. The under surface or bottom of the blue clay is in general, of course, the upper surface or top of the bowlder clay, except for the bed of sand or gravel, of no great thickness, which occasionally intervenes; and it is improbable that the maximum depth of this contact has yet been determined. There can be no doubt, however, that, since the clay must have been deposited in perfectly horizontal, even layers, and have covered the entire area to about the level of the highest point which it now attains, its maximum original thickness in the inner part of the harbor was not less than 200 feet.

On the draining of Lake Shawmut by the farther recession of the ice, the clay deposit, which was then still at a considerable elevation above the sea, was exposed to the air long enough (hundreds and probably thousands of years) to permit the Charles and other streams to erode valleys in it to maximum depths of 50 feet or more; and, since in this harbor area the preglacial channels of the rivers had been completely effaced by the deposition of the blue clay, the new channels are more or less independent of the old. This we have seen is markedly true of the lower or tide-water portion of the Charles. It was at this time, as the result of some relatively slight and wholly fortuitous inequality in the surface of the clay deposit or of the sand, a slight thickness of which was here and there spread over the surface of the clay in the closing stages of Lake Shawmut, that the Charles first began to follow its present course below the Harvard Bridge. That the erosion of the clay, producing all the depressions now occupied by the inner harbor, was subaërial and not marine — fluvial and not tidal — and that it extended over a long time, are indicated by the superficial yellowing of the clay through the oxidizing influence of the atmosphere; the oxidation extending commonly to depths of 0 to 10 feet below the present upper surface of the clay, even under the bed of the river.

This is an important point, since it proves conclusively that the estuary of the Charles is not due to tidal scour, but is the product of the river at a time when the land stood higher relatively to the sea than now.

During the subsequent slow subsidence of the land the erosion of the bed of the river ceased, and, instead of being further degraded, it was somewhat aggraded by the deposition of sand and fine gravel to varying depths; the borings for the Charles River bridges showing, resting unconformably upon the eroded surface of the blue clay, from 0 to 20 feet of sand and gravel, the prevailing thickness being from 5 to 10 feet. This deposit, which appears to become thicker landward and thinner and less continuous seaward, is probably in part marine — a beach formation, just as we may now find at various points about the harbor beaches of sand and gravel forming over the blue clay as well as the bowlder clay. In part, also, it may be regarded as residuary, an accumulation of the stones once incorporated with the blue clay which has been removed by fluvial erosion.

The harbor as we now know it came into existence with the subsidence of the land to approximately its present level, and the inner harbor, at least, is confined almost wholly to the valleys which had previously been formed by fluvial erosion in the blue clay. With farther subsidence, carrying these deposits below the sea level, the sand and gravel gradually gave way to the silt, or the black, carbonaceous, sandy mud or muddy sand, which everywhere forms the immediate floor of the harbor below the Boston base.

Since the blue clay is the principal deposit above the bowlder clay, it demands special consideration. Careful mechanical analyses of the blue glacial clay of this region show that it invariably contains a large proportion of quartz flour, which detracts but slightly from its clayey qualities, while adding to its value for brickmaking, etc., by tempering the clay. At its higher levels, and almost everywhere above the low-tide level, the clay has been, as previously noted, superficially oxidized to a buff or yellow color. The fact that the yellow or oxidized clay, and also the oxidized bowlder clay, is found from 10 to 20 and even 30 feet or more below low tide, indicates that the glacial lake was drained and the deposit exposed to the air for a long time before the land subsided to its present level relatively to the sea.

Both the oxidized and unoxidized clay are naturally of a very

stiff, tough, and impervious character; and this, together with the considerable weight which they bear, must keep them comparatively dry, or free from any excess of water. The oxidation makes the clay, and also the bowlder clay, harder and firmer, by cementing the clay particles with iron oxide; and this may explain the fact that the boring records often indicate "hard clay" above, passing downward through "stiff clay" to "soft clay." As regards its imperviousness, it must be noted that the formation as a whole in its natural position must be more impervious to the overlying water of the harbor than filtration experiments with a representative series of samples would indicate; because the stratification of the clay must be strictly horizontal, and the highly impervious or non-pervious layers of plastic clay prevent the water from gaining access to the occasional relatively pervious sandy layers.

One of the most interesting sections, as regards the light which it throws upon the relations of the blue clay, is that based upon the borings made preparatory to dredging on the southwest side of the Bird Island flats. This shows, toward the west end of the flats, and from the bottom upwards: first, bowlder clay, forming a well-defined valley, which is filled with, second, blue clay, the blue clay being soft below and passing upward through stiff to hard, the hard clay being rather thin, and in part yellow instead of blue, as the result of oxidation.

The Silt.

"Silt" is used here as a general name for the recent deposits (including those now forming), which are of a fine or muddy character. The blue clay is covered normally by 2 to 5 feet or more of soft, black (carbonaceous), sandy mud, or, more properly, a fine, muddy sand, which commonly contains shells or fragments of shells, and is thus strongly contrasted with the blue clay. Wherever streams had excavated hollows in the surface of the blue clay, these are partially or wholly filled with silt, which there attains an exceptional thickness — 15 to 20 feet in some cases. Other instances where this sandy silt has an exceptional thickness are best explained as due to the dredging of the silt and its use for filling. In some instances, also, the silt is less carbonaceous, and passes into a fine sand.

The silt is an entirely loose and uncompacted deposit, which is easily moved or drifted about, like sand on a beach, by the action of

the current; and hence areas from which it must once have been removed by dredging, as about the wharves, are now in general covered by it again, so that it is, in fact, a nearly universal deposit in this part of the harbor. That the silt is very sensitive to variations in the force of the currents is shown by the fact that in a more sheltered area, like the angle between the Charles and Mystic rivers, off the Navy Yard, it attains a much greater thickness — commonly 10 to 15 feet, with a maximum of 25 feet. The fact that the deposition of this relatively coarse material between Boston and East Boston is almost at a standstill now is proof sufficient that the deposition of the blue clay belongs entirely to the past, and to a somewhat remote past; for we have incontestable evidence that the deposition of this sandy silt began a long time ago and has witnessed a notable change in the relative levels of the land and sea. Innumerable borings and excavations in the low lands all about Boston and in the valleys of the Charles and Neponset rivers, etc., have shown that this highly fossiliferous silt, containing many shells no longer living in Boston Harbor, rests upon the blue clay and is covered by a considerable thickness of peat. The peat is largely now below sea level, and thus proves that a subsidence of the land has taken place. This postglacial subsidence, tending to deepen the harbor, has made the conditions increasingly favorable to the deposition of the silt.

The slow subsidence of the land which made the accumulation of the silt possible has continued during the whole period of its accumulation; and we have good reason to believe that this subsidence is still in progress, and that the silt is still accumulating. The average or normal rate of increase of a deposit of this character must, in the nature of the case, be extremely slow; and that it has been slow in this instance, and that it began a long time ago, is proved by the fact that it has not only witnessed a notable change in the relative levels of the land and sea, but also a notable climatic change, for it contains species of shells no longer living in Boston Harbor or north of Cape Cod. It is probably entirely within bounds to say that the deposition of the silt has covered a period of fully five thousand years, the rate varying according to the locality, from less than 1 foot to 5 feet in a thousand years.

It is easy to see that for any given locality the rate must diminish as the subsidence progresses and the depth of the water increases. Hence, except for the wastes from sewers and the greater

wash from streets and ploughed ground than from the natural forest covered drainage area, we may fairly assume that the rate of deposition at the present time for the estuary of the Charles is less than the average for the past. A rate above the normal is possible only in a relatively sheltered area, or where, through some change in the strength or direction of a current, silt that has been deposited is swept away, to be redeposited in a more quiet place. In other words, original deposition must be slow, and slower now than formerly, unless increased by artificial causes; and redeposition only may vary widely from the normal rate.

The silt, as now distributed, is in part distinctly or highly fossiliferous, and in part free or comparatively free from shells. Not infrequently the same boring shows it to be free from shells above, and shell-bearing below. Obviously, the most if not all of the shells are too heavy to be transported by the tidal currents, and hence where the silt is suffering erosion the shells are left behind, gradually forming a residuary accumulation or layer, which must tend to protect the silt from farther erosion, and the material which has been swept away is deposited in some more tranquil spot, free from shells. Hence the absence of shells may be regarded as an indication of transportation from the point where the material was originally deposited; and it is a safe conclusion that the erosion would have been much more extensive than it has been, but for the shells.

We have noted that the average rate of deposition of the silt must have been greatly reduced by the construction of sea walls, wharves, etc., in the harbor, and of dams on the river, and that the proposed dam would operate very efficiently to the same end by permanently cutting off a vast amount of material which might conceivably be swept out into the harbor, and, by diminishing the volume of the tidal reservoir, and consequently the movement of the tidal prism, lessening the power of the tidal currents to transport detritus remaining below the dam and exposed to their action. This principle appears still more important when we reflect that the chief source of detritus in the past has been, not the river, but the shores, islands and flats of the harbor. In other words, the prevailing movement has quite certainly been inward and not outward, the estuaries and bays being slowly but surely filled up and obliterated by contributions chiefly from the sea and not from the land. This conclusion is greatly strengthened by the obvious fact that the in-

coming tide must be the more efficient agent of detrital transportation, since, as has been confirmed by recent observation, the cold salt water of the flood must be heavier than, and consequently will have some tendency to flow beneath, the relatively warmer fresh water of the ebb tide.

A most striking illustration of the inefficiency of fluvial transportation in this region is afforded by the fact that the Mystic Ponds, occupying kettle holes, or depressions in the modified drift due to the melting of residuary and buried masses of ice, and therefore dating from the close of the ice age, have not been obliterated or even appreciably diminished in area by the action of the river during a period estimated at ten thousand years. In this connection we may also pertinently note that the shells in the silt not only protect it from erosion, but, like pebbles on a beach, favor its accumulation by affording in the dead water of interstitial spaces an opportunity for sand and silt to settle. The last thought suggests another. Apparently the shells in the silt are all dead, some of them, at least, having become so since the settlement of this region by Europeans, and probably as an incident, or indirect consequence, of the increasing density of the human population; and it may be doubted if, in the absence of its organic accompaniment, the accumulation of silt could continue at its normal rate on tide-swept areas. On the other hand, Dr. Field has pointed out that the extinction of some if not all of the molluscan types, and notably of the long oysters, was due to an excess of silt, the abnormal length of the oysters being interpreted as due to an unconscious effort on the part of the organism to keep pace with the growth of the sediment which finally overwhelmed it. This crisis might perhaps reasonably be explained as a consequence of the deforesting and cultivation of the land, making it more easily eroded. But the tendency is clearly in the opposite direction now, for shore defences, paved streets, intercepting sewers, the covering of extensive areas by buildings and the general restriction of cultivation to turf and trees must have greatly checked both marine and subaërial erosion, and, in consequence, the complementary process of deposition must be nearly at a standstill, so far as it depends upon land-derived detritus; and we have in future chiefly to guard against the inward transfer by the deep running flood tides of the immense deposit of silt in the outer harbor. Certainly one important means to this end is the reduction of the tidal reservoirs.

While the early development of civilization in this district probably tended, for the reasons stated, to accelerate the deposition of the silt and to extinguish the organisms characteristic of the older and deeper portions of the deposit, the later developments have undoubtedly operated to retard the deposition of the silt, even reducing it below its normal or pre-colonial rate; and we may anticipate that the tendency to shoaling will be diminished by the deepening and broadening of the channel by dredging now or recently in progress.

Conclusion.

That the waterways of the inner harbor are not due in any appreciable degree to the erosive action of the tides, and that wave erosion tends only to the obliteration of the channels, are propositions which should require no further argument. Postglacial deposition aside, the subaqueous contours are the product either of the glacial agencies in the laying down of the drift formation, or of the subaërial or stream erosion of the glacial deposits, and especially of the blue clay. That the erosion was subaërial is proved by a variety of features, — especially by its occurrence, in general, only where required by the existing drainage systems of the land; and by the superficial oxidation of both the bowlder clay and the blue clay, even where covered by a considerable depth of highly carbonaceous silt. The land valleys thus developed below the present level of the sea were drowned by the subsequent subsidence which made possible the deposition of the silt in them. That the rate of subsidence has, in the main, exceeded the rate of deposition of the silt, the channels deepening in spite of the deposition, is obvious, for otherwise the channels must have been filled and obliterated; and that the subsidence is probably still in progress is indicated by many facts noted on this and other parts of our coast, such as the submerged forests and peat beds, and the wearing away by the waves of aboriginal shell heaps and graves. But that the rate of subsidence has probably diminished would seem a safe inference, in view of the extensive development over the inter-channel areas of eel-grass flats, subsequently, in large part, converted into salt marsh, on which peat has formed more or less extensively. In fact, the breadth of fully developed marsh in some parts of the harbor, and the approximately uniform elevation of even our broadest beaches, such as Nantasket,

are suggestive of a good degree of stability at the present time;[1] and that the subsidence has been more or less intermittent is indicated by peat beds interstratified with the silt, and now 10 to 20 feet below the minimum elevation (high tide) at which peat can form. That the movement has not actually been reversed, or at least that the downward movement has dominated throughout postglacial time, is indicated by the facts stated, and also by the absence of the carbonaceous silt, with or without its characteristic fossils, above sea level.

That the silt deposition has in the past lagged far behind the subsidence is obvious, the average thickness of the silt being but a small fraction of the average depth of the harbor to the bottom of the silt. We are thus brought once more to the conclusion that only redeposition of the silt, or its transfer from one point to another, like drifting snow, can lead to appreciable shoaling of the harbor.

The argument that if the tidal scour were diminished, as it would be by any reduction of the tidal reservoir, Boston Harbor would fill up and become shallow, like Quincy and Dorchester bays, where there is very little tidal scour, is based on the assumption that these bays were once deep, and have silted up. But this assumption is wholly unwarranted. In the case of Quincy Bay, between the Neponset River and Weymouth Fore River, there is no tributary stream of sufficient magnitude to have excavated, during the time when the coast was more elevated, channels comparable in depth and breadth with the lower estuary of the Charles. The known facts indicate, rather, that the low sand plain of North Quincy extends eastward under this part of the harbor, affording a foundation for the broad areas of eel grass, in the meshes of which some mud has been slowly entrapped; but that the mud or silt has attained important thickness is improbable.

In Dorchester Bay it appears, from the borings made in connection with the construction of the main drainage tunnel, that in ancient times, prior to the general subsidence of the district, the Neponset River excavated a channel in the blue clay to a depth of

[1] As previously referred to, the State geologist of New Jersey has deduced from varied and manifold data a probable rate of subsidence of the coast in the vicinity of New York Harbor at the present time of about 2 feet per century; and yet the beach and marsh developments of that coast are fully equal to those of Boston Harbor.

between 50 and 60 feet below the present low-tide level, and that in this channel the silt now has a maximum thickness of about 25 feet. It should be noted, however, that, encircled as it is by land largely composed of modified drift in the form of fine sand, the conditions have here been exceptionally favorable to the comparatively rapid accumulation of the silt. It is easy to see that, during the slow submergence of such low, sandy tracts as we have in North Quincy and the eastern part of Dorchester, the sand would be worked over extensively and deeply by the waves, and much carbonaceous mud incorporated with it, and the sandy silt thus developed at a much more rapid rate than would be possible after submergence became an accomplished fact.

The bowlder clay which elsewhere constitutes so large a part of the shores of the harbor, particularly around the upper harbor, and the lower part of the estuaries of the Charles and Mystic, erodes much more slowly, and, when worked over, as during the slow subsidence, yields to the waves chiefly stones and gravel which remain on the beach, and quartz flour and clay which cannot settle in the tidal channels, but are likely, so far as not entrapped in the meshes of the eel grass, to be swept out to sea by the ebb, and deposited in deep, quiet water off shore. This enables us to understand how it is that the channels of the inner harbor have survived submergence, and that in some cases they are almost bare of silt. It is especially interesting to note that on the shores of the inner harbor, in Boston, Charlestown, East Boston and South Boston, easily eroded, sandy drift is conspicuous by its absence, and the floor of this part of the harbor is but lightly covered by silt; but above the Charlestown bridges, in Cambridgeport and Brookline, the shores are largely fine sand, and the upper portion of the estuary of the Charles is deeply silted above the surface of the blue clay.

A SYSTEM OF QUALITATIVE ANALYSIS INCLUDING NEARLY ALL THE METALLIC ELEMENTS.

By ARTHUR A. NOYES.

(Preliminary Publication.)

INTRODUCTION.

The aim of this investigation has been to work out in detail a systematic, universally applicable scheme of qualitative analysis which shall include as nearly as practicable all the metallic elements, and which shall make possible their detection even when present in quantity as small as one or two milligrams.

The great importance, both from a technological and a purely scientific standpoint, which has become attached in recent years to many of the "rare elements" — so called often only by reason of their traditional and somewhat arbitrary exclusion from the usual schemes of qualitative analysis — has made it highly desirable that a systematic and reliable method for their detection be available. Any chemist who, without previous experience in this field, has occasion to test for small quantities of these elements will infer upon consulting the existing literature, and become convinced when he begins to experiment, that his problem is beset with difficulties and will require much time for its solution.

Until within a few years, aside from the brief outlines given in the text-books on Qualitative Analysis of Rose, Fresenius, Classen, and a few other writers, nothing like a systematic scheme of analysis existed; and it was necessary for the analyst to apply as best he could the isolated separations and tests recorded in such text-books and in the journals. In 1898 Carnot published in his "Traité d'analyse des substances minérales" a scheme of qualitative analysis which included all the more important rare metals. But none of these methods seem to have been subjected to any adequate investigation with reference to the effectiveness of the separations or the reliability and delicacy of the tests; moreover, in a field of work where

the closest adherence to the proper conditions is essential to success, the directions given are of a most general character. These schemes, therefore, when tested in the laboratory, are found to be seriously defective, and to have little practical value, except for the detection of large quantities of some of the rare elements. A vast amount of valuable work has, of course, been published upon the separation of the rare elements of separate groups, like the rare-earths, the platinum-metals, and the rarer alkali-metals; but this work has been done mainly from the standpoint of quantitative analysis and with reference to the limited number of elements which are found associated in certain important minerals or ores. Of the systematic procedures devised for qualitative purposes ought to be mentioned, however, those of Mylius and Dietz (*Ber.*, **31**, 3191. 1898) and of Leidié and Quennessen (*Bull. soc. chim.* (3) **27**, 181. 1902) on the platinum metals, and of Possetto (*Chem. Centralb.* 1898, **1**, 634) on the rare-earths. These quantitative and qualitative investigations have furnished many of the data necessary for the working out of a complete system of qualitative analysis, such as that which forms the object of this investigation.

This work has been in progress for over three years, and has been carried on in large part by research assistants and advanced students, whose valuable aid will be given recognition in connection with the separate groups of metals upon which each worked. The investigation has been liberally assisted by grants from the Warren Fund of the American Academy of Arts and Sciences, and will be published in its final form in the Proceedings of that Academy. It has been thought advisable, however, to make in this journal a preliminary publication of the work, as fast as integral portions of it are brought into satisfactory shape, so that the method may be available at once to those who may desire to use it. The work upon it will be continued, in order to test it more thoroughly and to improve it in matters of detail; but it is not likely that the procedure will be radically modified.

The results will be presented in the form that seems best adapted to the purposes of the analyst. The System of Analysis will be primarily divided into a series of Parts, in each of which will be described, as a rule, the detection of the elements precipitated or otherwise separated by a group reagent. Part I will treat of the Preparation of the Solution; Part II, of the Analysis of the Tung-

sten and Niobium Groups; Part III, of the Analysis of the Selenium and Silver Groups; Part IV, of the Analysis of the Platinum Group and the Detection of Lead and Tellurium; Part V, of the Analysis of the Ruthenium, Iridium, Copper, and Molybdenum Groups; and the succeeding Parts, of the Rare-Earth, Aluminum and Iron, Alkaline-Earth, and Alkali Groups. Under each Part is first presented a Tabular Outline which will give a survey of the important steps and the chemical reactions involved in the procedure. This is followed by a General Discussion, in which are presented the reasons for the adoption of the process employed. Then comes the Procedure itself, and the explanatory Notes upon it. Next are presented Confirmatory Experiments and References, which serve to substantiate the statements made in the Notes and to justify the details of the Procedure. Finally are given the Test Analyses, which were made with known mixtures according to the procedure, in order to test its efficiency.

The reader who wishes only to get a general idea of the method and its efficiency will find that the chapters entitled "Tabular Outline," "General Discussion," and "Test Analyses," will suffice for his purpose. The actual analyst will utilize especially those entitled "Tabular Outline" and "Procedure and Notes." Only to investigators in similar lines, or to those who seek the justification of the statements made in the Notes will the chapters on "Confirmatory Experiments and References" be of interest.

The operations are described in the Procedures in much detail; and the reasons for them, the theoretical principles involved, and other incidental matters are presented very fully in the Notes. It may well seem to experienced analysts that the writer has gone to an extreme in this respect: but, in the first place, attention to not obvious details is really essential in many cases in order to secure delicacy of the tests; and, secondly, it has seemed best to make the scheme as effective as possible in the hands of chemists with little experience in this kind of work, even though it involves in some cases rather lengthy descriptions. Even with such a full description, a knowledge of the manipulation of exact qualitative analysis is essential, in order to enable one to detect small quantities of some of the elements. Before analyzing an unknown substance, any one using the method for the first time should apply the procedure of each group to a known mixture containing two or three milligrams of each element.

The directions are almost always given in the form applicable to the case where all elements that could be present are present, the modifications admissible when certain operations lead to negative results being usually sufficiently evident. The scheme is divided into a number of separate "Procedures," a new one being begun whenever the substance has been resolved into two parts (such as a precipitate and filtrate) which are to be submitted to different operations, or whenever two or more collateral procedures converge to a single one. In order to make it possible to see at once the proper sequence of the procedures in an actual analysis, they are numbered consecutively in the description (except that some numbers are omitted at the end of each Part to facilitate subsequent revision); and at the beginning of each procedure the one by which the substance was last treated, and at the end of each procedure those by which the two separated portions of it are next to be treated, are referred to by number.

Most of the experiments described under "Confirmatory Experiments and References" are undoubtedly merely confirmations of previously known chemical facts. The application of these facts to the specific conditions of the procedures it was, however, constantly necessary to test; and it has seemed worth while to make the results a matter of record. The experiments are preceded by a reference to the procedure and note to which they relate.

Of the abbreviations employed, only a few need be explained: G. D. is used for General Discussion; P., for Procedure; N., for Note; C. E., for Confirmatory Experiments; T. A., for Test Analyses. A number within parentheses expresses the specific gravity at 15°: even with diluted acids, the concentration is for brevity usually indicated in this way; thus HCl (1.02) means an acid made by mixing one volume of HCl (1.12) with five volumes of water. When it is directed to add a variable quantity of a reagent (for example, 5–15 ccm.), the amount used should be adjusted to the size of the precipitate or residue. Certain brief expressions commonly employed in the procedures are fully explained, especially with reference to the manipulative details, under one of the first procedures where they occur; for example, see P. 3, N. 2, as to the exact significance of "evaporate just to dryness," P. 5, N. 6, as to that of "wash the precipitate."

TABULAR OUTLINE.

Non-metallic substance: *Heat 1 gm. with HNO_3 (1.20), dilute and filter.* (*P. 1.*)

Metallic substance: *Heat 0.5 gm. with HNO_3 (1.20), evaporate, and heat at 120°.* (*P. 4.*)

Residue: *Heat with HF, evaporate with HNO_3, and add HNO_3 (1.05); (if insoluble fluorides remain, digest with SiO_2;) evaporate, and heat at 120°.* (*P. 3.*)

Solution: *evaporate, and heat at 120°.* (*P. 2.*)

Dehydrated residue: *Heat with HNO_3 (1.20), dilute, and filter.* (*P. 5.*)

Solution: all elements except Si, Nb, Ta, W, Sn, Os, and most of the Sb and Ti. (*P. 51.*)

Residue: *Heat with HF, dilute, and filter.* (*P. 6.*)

Solution: niobium and tungsten groups, (Nb, Ta, Ti, W, Sn, Sb); sometimes also P, As, Bi, Se, Te, V, Mo, Ge. (*P. 31.*)

Residue: MnO_2, PbO_2, HgS, Au, and the substances named below under "residues." *Boil with HCl (1.20), then with aqua regia, dilute, and filter.* (*P. 7.*)

Solution: *evaporate, add HCl (1.02), filter.* (*P. 17.*)

Solution: chlorides of Pb, Mn, Hg, Au, Pt. (*P. 71.*)

Residue: AgCl, $PbCl_2$, $PbSO_4$, $BaSO_4$, $SrSO_4$. (*P. 18.*)

Light-colored non-metallic residue: $BaSO_4$, some silicates, Al_2O_3, TiO_2, $ZrSiO_4$, SnO_2, ThF_4, monazite. *Fuse with Na_2CO_3; heat with water, and filter.* (*P. 9.*)

Solution: (*P. 11.*)

Residue: *add HCl and filter.* (*P. 10.*)

Solution: (*P. 71.*)

Residue: *Fuse with $K_2S_2O_7$.* (*P. 12.*)

Dark-colored or metallic residue: C, SiC, MoS_2, $FeCr_2O_4$, $Fe_7(CN)_{18}$, Pt, Ir, Os, Rh, Ru, $FeSi_x$, $FeCr_x$, etc. *Fuse with Na_2O_2, add water and HCl, and distil into NaOH.* (*P. 13.*)

Distillate: OsO_4. (*P. 14.*)

Residual solution: (*P. 15.*)

General Discussion.

Much effort has been devoted to determining the best general method for the preparation of a solution of an unknown substance for the analysis for the metallic elements. That some definite method be adopted for this purpose is an essential preliminary to the working out of a general system of analysis, especially when the rare metals are to be included; for the subsequent division into groups must depend to some extent upon the nature of the acids employed as solvents. The aim has been to devise a method of preparing the solution, which in its actual application to substances ordinarily met with shall be as rapid as possible, which shall be so general and so fully developed as to effect the solution of practically all known substances, and which shall adapt itself to sharp and convenient group-separations in the subsequent system of analysis.

In the usual, well-known method of procedure with a non-metallic substance this is heated successively with water, dilute and concentrated hydrochloric acid, nitric acid, and aqua regia. Then the residue, if blowpipe tests show the absence of much reducible metal, is fused in a platinum crucible with sodium carbonate; or, if reducible metal is present, to remove it the residue is first treated with special solvents like potassium cyanide and ammonium acetate, and is then fused in a platinum crucible; or, if the use of such solvents is inconvenient or ineffective, the residue is fused in a porcelain crucible, whereby the constituents of the crucible are introduced. Finally, any residue undecomposed by the carbonate fusion is fused with such special fluxes, potassium disulphate, sodium carbonate and nitrate, sodium carbonate and sulphur, as the apparent nature of the residue suggests. It will be seen that this procedure is very different from the one summarized in the Tabular Outline given above, which has been adopted as a part of the new System of Analysis. The advantages of the proposed modifications should therefore be presented.

An important consideration having a direct bearing on the procedure to be adopted for the preparation of the solution must be

first mentioned. This has reference to the fact that certain oxides, namely, those of silicon, tungsten, niobium, and tantalum, do not dissolve, or at any rate do not remain in solution, in the dilute mineral acids commonly employed; so that, when a substance containing these oxides has been brought into solution by an alkaline fusion or treatment with a special acid like concentrated sulphuric or hydrofluoric acid, they separate upon neutralization of the alkali or upon dilution or replacement of the acid, either immediately or in some subsequent stage of the analysis. This fact has been ignored in the previous schemes of analysis outlined for the rare elements; thus tungsten, in spite of the insolubility of its oxide in acids, is provided for either in the ammonium sulphide solution of the hydrogen sulphide precipitate, or in the filtrate from the ammonium hydroxide and sulphide precipitate; niobium and tantalum, which are bound to precipitate through hydrolysis of their salts when the solution is diluted and heated in the precipitation with hydrogen sulphide, are commonly included among the elements precipitated by ammonium hydroxide. It is therefore essential, unless these elements are to be allowed to appear somewhat capriciously at different points in the analysis, to remove them at the start. In order to do this completely, however, it is necessary to evaporate the solution to complete dryness, in order to dehydrate their hydroxides and make them completely insoluble in dilute acid. Even though it is true that certain other elements divide themselves between such a residue and the solution, and must be provided for in the subsequent analysis of both portions, this is a far less serious objection than that justified by the failure to provide for the certain detection of tungsten, niobium, and tantalum. It is for this reason that the first series of operations after the decomposition of the substance with strong acids is directed to effecting the removal of the group of elements whose dehydrated hydroxides are insoluble in dilute acid.

The first solvent employed in the proposed method (P. 1) is nitric acid, not hydrochloric acid, the most cogent reason for this being that, if the latter acid were used, certain elements, namely, arsenic, selenium, germanium, mercury, and gallium, would be wholly or partly lost in the subsequent evaporations, owing to the volatility of their chlorides. Hydrochloric acid also has the disadvantage of causing the precipitation of silver, lead, mercurous, and thallous chlorides, and thereby making it impossible to determine whether com-

plete decomposition has been effected. Nitric acid, owing to its oxidizing power, is, moreover, a more general solvent; but it does on this very account have the disadvantage of oxidizing sulphides to sulphates and causing the separation of the insoluble sulphates of lead, barium, and strontium; and it is to reduce the amount of this oxidation and to make certain crystalline nitrates, like those of lead and barium, more soluble, that a somewhat diluted acid of the specific gravity 1.20 is recommended. Furthermore, nitric acid, unlike hydrochloric acid, leaves all the tin and almost all of the antimony in the insoluble portion of the dehydrated residue.

The first residue insoluble in nitric acid is not treated at once with aqua regia, because the latter solvent decomposes very few substances unacted upon by the former; because the disadvantages of hydrochloric acid just specified apply to its use in some degree; and because any residue undissolved by it, especially if not thoroughly washed, might retain chlorides which would cause the platinum vessel necessarily used in the next treatment with hydrofluoric acid to be attacked.

The residue undissolved by nitric acid is treated with hydrofluoric acid for the reason that this forms a simple method of dissolving silica and almost all silicates, which otherwise would have to be decomposed by a fusion with sodium carbonate or some other flux. The fusion with sodium carbonate has the disadvantages that the operation is less convenient; that it introduces alkali-metals into the solution, which must therefore be tested for in a separate solution prepared in some other way; and that, before the fusion can be carried out in a platinum crucible, the residue must be tested for reducible metals, and, if they are present, freed from them, as far as possible, by treatment with special solvents, like hot concentrated hydrochloric acid or ammonium acetate and potassium cyanide solutions. If, however, it is not desired to test for alkali-metals, and if reducible metals are probably absent, the residue insoluble in nitric acid (P. 1) may, if the sodium carbonate fusion is preferred to the treatment here described, be treated at once by P. 7 and then by the subsequent procedures.

Both the free and combined hydrofluoric acid must next be completely removed, in order to proceed satisfactorily with the analysis; for, otherwise, partial solution of the oxides of the tungsten and niobium groups would take place, and the glass vessels used in subse-

quent operations would be attacked. Its removal might be easily accomplished by a single evaporation with sulphuric acid to the point of strong fuming; and this would have the advantage of decomposing a few other substances (such as monazite and thorium fluoride) that are not much attacked by hydrofluoric and nitric acids. A great many experiments were made to test the applicability of this process of decomposition, so much used in quantitative work, to the purposes of qualitative analysis. It was abandoned, however, because the introduction of sulphuric acid complicates the subsequent procedure by preventing the complete separation of the hydroxides of certain elements of the tungsten and niobium groups when the acid is diluted, and by causing the precipitation of some basic sulphates as well as that of the insoluble neutral ones before it is certain that complete decomposition of the substance has been effected. Its abandonment was, moreover, made possible by the discovery of an alternative method of decomposing the insoluble fluorides. It was found, namely, that all of these, except thorium fluoride, are destroyed by concentrated nitric acid when its action is supplemented by the addition of finely divided silica. This substance evidently acts by combining with the hydrofluoric acid liberated by the strong nitric acid, thus enabling the reaction to become complete, in accordance with the Mass-Action Law; it was, in fact, this theoretical consideration that suggested its use.

With by far the larger proportion of substances apt to be submitted to analysis, any portion of the dehydrated residue that may be undissolved by dilute nitric acid (P. 5) consists only of silica and oxides of the tungsten and niobium groups, and dissolves completely when it is treated with hydrofluoric acid (P. 6). Still less frequently will there be a residue after the next treatment with hot strong hydrochloric acid and aqua regia (P. 7); for almost all of the fairly common substances previously unacted upon, such as manganese and lead peroxides, mercuric sulphide, silver chloride, lead, strontium, and barium sulphates, gold and platinum, are dissolved by these acids. The lengthy description of subsequent procedures, which is added in order to provide for nearly every possible case, must not, therefore, give the impression that the method here adopted is in its ordinary application long or complicated.

Of the subsequent fusions necessary in special cases, only that with sodium peroxide (P. 13) need receive any general discussion.

This flux, suggested by the work of Leidié and Quennessen (*Bull. soc. chim.* (3), 27, 181. 1902) was adopted, because it undoubtedly furnishes the best solution of the difficult problem of bringing the rarer platinum metals into a soluble form. The process usually employed for this purpose consists of two parts: the metal is first brought into a fine state of division by fusing it with a large quantity of lead and treating the fused mass with nitric acid; the residue is then intimately mixed with sodium chloride, and heated to a dark red heat in a current of chlorine. Both parts of this process are extremely tedious and likely to yield incomplete results, even when only half a gram of metal is to be treated. On the other hand, when the metal is to be fused with sodium peroxide, mechanical processes readily reduce it to a sufficiently fine state of division, and the fusion need not be continued for more than twenty minutes. It is true that the nickel crucible, in which the fusion is best carried out, is much attacked by the flux; but the presence of nickel does not interfere at all with the detection of the platinum metals or of the other elements which are precipitated by hydrogen sulphide, nor does it interfere very seriously with the detection of the elements present in the precipitate produced by ammonium hydroxide or sulphide, since they can be separated from almost all of the nickel by treating the precipitate with dilute hydrochloric acid. It may be added that, before finally adopting this procedure, a few experiments were made on metallic iridium with the hope of effecting its solution by heating it to 200° in sealed tubes with bromine or with a mixture of bromine and concentrated hydrobromic acid; but the quantity dissolved was insignificant.

In concluding this chapter, it is a pleasure to add that I have been ably assisted in this part of the work by Messrs. J. E. Ober, G. V. Sammet, and W. H. Whitcomb.

Procedure and Notes.

Procedure 1. — If the substance is a metal, treat it by P. 4.

If the substance is not a metal, proceed as follows: Grind about 1.5 gm. in small portions in an agate mortar until it is so fine that no grit is perceptible when a little of it is rubbed between the fingers. Weigh out roughly about 1 gm. into a casserole, pour over it 10 ccm. HNO_3 (1.20), cover the dish, and digest the mix-

ture on a water-bath for 15 minutes, or as long as an action appears to be taking place. [If, however, it is thought necessary to test for the presence of osmium in the form of a salt, boil the substance in a distilling flask with HNO_3, and collect and test the distillate by P. 13 and P. 14.] Then add 20 ccm. boiling water, and allow the residue to settle. [If a light-colored spongy mass of sulphur has separated, remove it by means of a rod or spatula.] Decant the liquid through a filter. If HNO_3 seemed to be slowly attacking the residue, digest it with a fresh portion of HNO_3, dilute, and decant as before. Wash the residue with hot water twice by decantation, pouring the washings through the filter. Transfer the residue from the casserole and filter to a platinum dish by rinsing with a little water. Decant or evaporate off the water. (Solution, P. 2; residue, P. 3.)

Notes. — 1. In order to secure the decomposition of difficultly decomposable substances by the following procedures, it is of fundamental importance that the substance be reduced to a literally impalpable powder, a result that can often be obtained only by the long-continued grinding of the substance in small quantities at a time.

2. One gram of the substance is usually taken; for, since 1–2 mgm. of almost any element can be detected by this system of analysis, with one gram the presence of as little as 0.1–0.2% can be determined, which is ordinarily sufficient. It is treated with the acid in a porcelain vessel because of the possible presence of chlorides, which would attack the platinum vessel which has to be used in the subsequent HF treatment (P. 3). The HNO_3 solution is decanted and the residue is washed for this same reason, and also because in many cases the elements which form insoluble fluorides, of which calcium is the most common, are thereby removed, so that the subsequent treatment with SiO_2 (P. 3) becomes unnecessary. The treatment in a distilling flask when osmium can be present as a salt is to avoid the loss of this element by volatilization, as OsO_4. See P. 13, N. 9.

3. If HNO_3 attacks the substance with separation of a white precipitate, the latter may consist of hydrated SnO_2, Sb_2O_5, SiO_2, TiO_2, GeO_2, Nb_2O_5, Ta_2O_5, MoO_3, or of $BaSO_4$, $PbSO_4$, $SrSO_4$. Certain nitrates, especially $Pb(NO_3)_2$ and $Ba(NO_3)_2$, may also separate in crystalline form from the strong HNO_3; but these dissolve upon adding water and heating to boiling. If a dense yellow decomposition-product results, it probably consists of H_2WO_4. A spongy mass which becomes pasty on boiling the solution is sulphur.

4. If a portion of the substance is not attacked by HNO_3 (1.20), it probably consists of one or more of the following substances: the oxides and sulphates named in N. 3; the native or ignited oxides of aluminium, chromium, and zirconium; the peroxides of manganese and lead; the silicates and fluosilicates of many elements; sulphide of mercury; fluoride of calcium; the halides of silver; ferrocyanide of iron; carbon; silicon carbide.

Procedure 2. — Evaporate the HNO_3 solution (P. 1) as nearly to dryness as is possible without overheating the residue. Heat in a hot closet at 120° for one hour, or longer if the mass has not then become perfectly dry. (Residue, P. 5.)

Note. — 1. The evaporation to dryness and heating in the closet at 120° serve to dehydrate and make less soluble in HNO_3 silica and the hydroxides of the elements of the tungsten and niobium groups, which may at first be dissolved by the HNO_3. If the dry residue were strongly heated over a flame, mercury compounds might be volatilized, and iron, aluminium, and chromium oxides made insoluble.

Procedure 3. — Add to the residue insoluble in HNO_3 (P. 1) 5–10 ccm. pure concentrated (40%) HF solution, and digest on a water-bath for 15 minutes. Note whether complete solution takes place. Add 5 ccm. HNO_3 (1.42), and evaporate just to dryness. Cover the residue with HNO_3 (1.42), and again evaporate just to dryness. Add 10 ccm. HNO_3 (1.05), and heat to boiling.

If complete solution took place either on the addition of the HF, or if it occurs on the treatment with the HNO_3 (1.05), evaporate just to dryness a third time; then heat the dish for at least one hour in a hot closet at 120°.

If neither the HF nor the HNO_3 (1.05) produced a perfectly clear solution, evaporate the liquid just to dryness, loosen the particles from the dish, add 10 ccm. HNO_3 (1.42) and 1 gm. pure, ignited precipitated silica, cover the dish, and digest on a water-bath for three-quarters of an hour. Then evaporate the liquid just to dryness, and heat the dish for at least an hour in a hot closet at 120°. (Residue, P. 5.)

Notes. — 1. The HF used must leave no residue whatever after evaporation and gentle ignition, since otherwise foreign elements would be introduced. It must not contain H_2SO_4 in considerable amount.

since otherwise $BaSO_4$ and $PbSO_4$ may be left undissolved on the subsequent treatment of the dehydrated residue with HNO_3 (P. 5) and HF (P. 6), and since some of the hydroxides of the niobium and tungsten groups may dissolve. The presence of H_2SO_4 in it may be detected by adding to 3 ccm. of it 10 ccm. HCl (1.03) or 20 ccm. HCl (1.02) and 1 ccm. 10% $BaCl_2.2H_2O$ solution.

2. Whenever, as in the above procedure, it is directed to evaporate a solution "just to dryness," this should be done in such a manner as not to heat any portion of the dried residue much above 100°. This may be accomplished by heating upon a steam-bath, or more rapidly over a small flame, provided proper care be taken; in the latter case, after the solution has been reduced to a small volume, the dish must be kept constantly in motion so that the heated parts of the sides as well as the bottom are always wet with liquid, and when nearly dry the dish must be often removed from the flame and shaken in the air, so that the final evaporation will take place at as low a temperature as possible.

3. If the substance is decomposed by HF with the separation of a white precipitate, this indicates the presence of lead, bismuth, lithium, magnesium, or of an element of the alkaline-earth or rare-earth group. If no such precipitate separates, it shows the absence in quantity as large as one milligram in the part of the original substance insoluble in HNO_3, of lead, bismuth, calcium, and all the elements of the rare-earth group. Since LiF, MgF_2, SrF_2, and BaF_2 are somewhat soluble, these precipitates separate only in the presence of considerable quantities of the elements — in the presence of, roughly, 5 mgm. Li, 2 mgm. Mg, 8 mgm. Sr, 30 mgm. Na, when 5 ccm. HF are used.

4. The HF solution must not be evaporated to dryness without the addition of HNO_3; for much titanium and tantalum would then volatilize as TiF_4 and TaF_5. In the presence of HNO_3, however, the loss of these elements is inconsiderable, undoubtedly owing to the fact that this acid decomposes their fluorides. In the evaporation with HF and HNO_3 there is no loss of mercury, arsenic, selenium, germanium, or antimony — the elements which volatilize to some extent out of a boiling concentrated HCl solution.

5. If complete solution takes place on the addition of HF, the three evaporations with HNO_3 remove the HF completely, even in the presence of the elements titanium, niobium, tantalum, which have a great tendency to form complex fluorine-containing acids. In that case, the treatment with SiO_2 can be dispensed with; and this is desirable, whenever practicable, both because it saves time at this point and because it makes it possible to determine immediately upon the treatment of the dehydrated residue with HNO_3 whether or not elements of the tungsten and niobium groups are present.

6. In case the HF precipitate consists of even large quantities (500 mgm.) of PbF_2, BiF_3, LiF, MgF_2, SrF_2, or BaF_2, or of a small quantity (less than 50 mgm.) of CaF_2, the two evaporations decompose it completely, so that these elements pass into solution on adding dilute HNO_3, and the addition of SiO_2 is unnecessary.

7. If oxides of the tungsten and niobium groups are alone present in the first residue, these (with the possible exception of SnO_2) will yield a clear solution upon the treatment with HF (see P. 6, N. 1), but will again separate after the evaporations with HNO_3; in this case, in which HF, but not HNO_3, yields a clear solution, it is, of course, also unnecessary to treat with SiO_2.

8. When, however, CaF_2 or rare-earth fluorides separate in considerable quantity on the addition of HF, it is not practicable to decompose them by repeated evaporations with HNO_3 alone. But the addition of SiO_2 and digestion with it and strong HNO_3 effect complete decomposition of all the fluorides (except ThF_4, which may remain partially undecomposed as a dense crystalline powder). The SiO_2 combines with the HF that is liberated by the HNO_3, and thus, in accordance with the Mass-Action Law, enables the decomposition to become complete.

9. CaF_2, even when present in considerable quantity after the two evaporations with HNO_3, may yield a homogeneous, slightly milky colloidal solution upon the addition of dilute HNO_3. This must not be mistaken for a true solution, the production of which alone warrants the omission of the SiO_2 treatment.

10. The SiO_2 used must leave no residue whatever upon treatment with HF and evaporation of the solution. It may be prepared by diluting commercial water-glass with three times its volume of water, adding HCl as long as precipitation continues, decanting, boiling the precipitate two or three times with water, drying it in a hot closet, heating it two or three times with HCl (1.20), washing it till free from acid, drying it in a hot closet, and finally igniting it.

11. The heating at 120° is necessary in order to make silica and the oxides of tin, tungsten, and tantalum entirely insoluble in HNO_3. This is even more necessary after they have been dissolved by HF than when treated with HNO_3 alone. If the residue were overheated during the evaporations, other oxides, like those of iron, aluminium, and chromium, might not dissolve completely on the subsequent treatment with HNO_3.

Procedure 4. — If the original substance is a metal, convert it into a form that offers as much surface as possible by grinding it in an agate mortar, hammering it in a "diamond" steel mortar, filing it with a fine steel file, shaving it with a knife, or converting it

into borings with a drill. Weigh out roughly about 0.5 gm. into a casserole, pour over it, very gradually if a violent action occurs, 10 ccm. HNO_3 (1.20), cover the dish, and heat the mixture on the water-bath as long as any evolution of nitrous fumes occurs, adding more acid if the action is renewed thereby, or a little water if crystalline salts have separated. Then evaporate the liquid just to dryness, and heat the residue in a hot closet at 120° for an hour, or longer if the mass has not then become perfectly dry. (Residue, P. 5.)

Note. — 1. See P. 1, N. 3 in regard to precipitates that may separate during the HNO_3 treatment, and P. 3, N. 11 in regard to the dehydration of the residue.

Procedure 5. — Loosen the dehydrated residue (P. 2, 3, or 4) from the dish, and rub it to a fine powder with a pestle; add to it 5 ccm. HNO_3 (1.20), or 10 ccm. if it seems necessary, cover the dish, and heat on a steam-bath for 10 minutes. Note whether there is any residue whatever. If no residue can be seen, rub the sides of the dish with the rubber-covered end of a glass rod, and allow the liquid to stand 3 or 4 minutes. If there is a crystalline residue of nitrates, add enough water to dissolve it, and note whether an amorphous residue remains. Dilute with 20 ccm. water, and heat to boiling. If the substance was a non-metallic one, unite at this point the two portions (treated by P. 2 and P. 3), unless it is desired to know their constituents separately. Decant the solution through a washed filter, retaining in the dish as much of the residue as possible. If the residue is large in amount, heat it again with 5 ccm. HNO_3 (1.20), dilute with water, and decant the solution through the same filter. Wash the residue with HNO_3 (1.05), decanting the washings through the filter; and transfer it to a platinum dish. (Residue, P. 6; solution, P. 51.)

Notes. — 1. If SiO_2 has not been added, important conclusions can be drawn in regard to the absence of certain elements in the substance when nothing whatever remains undissolved upon treating the dehydrated residue with HNO_3 (1.20). The fact must not be overlooked, however, that in the dehydrated form even a very small residue or slight turbidity may correspond to an appreciable quantity of an element. A perfectly limpid solution and one that does not deposit any sediment whatever after a few minutes' standing must be obtained, if such conclusions are

to be drawn. Moreover, it should be noted whether such a solution results before diluting the HNO_3 (1.20) with water (or after diluting it with as little water as suffices to dissolve crystalline nitrates); for any residue is more difficult to recognize in a large volume of liquid.

In case no residue whatever remains, it shows the absence of silicon, tin, niobium, and tantalum in quantity as large as 1 mgm.; of antimony in quantity as large as 2 mgm., except when an organic hydroxy-acid is present; and of tungsten in quantity as large as 1 mgm., except when phosphoric or arsenic acid or an organic hydroxy-acid is present. It also indicates the probable absence of titanium in quantity as large as 1 mgm., except when zirconium is present.

Organic hydroxy-acids, like tartaric, lactic, and citric acids, dissolve Sb_2O_5 and H_2WO_4 with great readiness. H_2WO_4 also dissolves very readily when H_3PO_4 or H_3AsO_4 is present, owing to the formation of complex acids. The presence of arsenic, phosphoric, and organic acids is detected in the course of the subsequent procedure. Boric acid does not increase the solubility of any of the oxides of the tungsten and niobium groups. Moreover, it will not be present if the substance has been treated with HF; for even 1 gm. H_3BO_3 volatilizes completely upon evaporation with 5 ccm. of this acid and 5 ccm. HNO_3 (1.42). Even 500 mgm. of titanium may dissolve completely in the HNO_3 when much zirconium (500 mgm.) is present.

2. If SiO_2 has been added, the presence or absence of the tungsten and niobium groups cannot be determined until the residue insoluble in HNO_3 has been treated with HF, the solution evaporated with H_2SO_4, and NH_4OH and $(NH_4)_2S$ added (P. 6 and Part II).

3. The residue insoluble in HNO_3 may contain in addition to the oxides of the elements named in N. 1 the following substances: MoO_3, when molybdenum is present in quantities over 100 mgm., or when tungsten or tin is also present; GeO_2, when over 30 mgm. Ge are present; Bi_2O_3, when much antimony is also present; SeO_2 and TeO_2, when much tin or antimony is also present; ThF_4, when much thorium is present in the residue treated with HF; the phosphates and arsenates of tin, titanium, zirconium, and thorium, and the vanadate of tin, when the components of these substances are simultaneously present. The residue may also contain certain undecomposed substances (named in P. 6, N. 2) which are not attacked by either HNO_3 or HF.

4. Of the elements named in N. 3 which may under the specified conditions be present in the residue insoluble in HNO_3, the following ones always pass into the HNO_3 solution in considerable proportion when large quantities of them are present: molybdenum, bismuth, selenium, tellurium, zirconium, thorium, vanadium, germanium. This is also

true of titanium (N. 1). Furthermore, a small quantity of antimony (1–2 mgm.) dissolves. Phosphoric, arsenic, and vanadic acids are dissolved completely when tin, titanium, and zirconium are absent.

5. Aside from the elements named in N. 1, and under the specified conditions aside from those named in N. 3, no others are retained in the residue insoluble in HNO_3 in important quantity, as far as is known. Even the elements bismuth, tellurium, zirconium, and thorium, whose salts are readily hydrolyzed, dissolve completely when present alone in quantities up to 500 mgm. This is also true of zirconium, even when 500 mgm. Ti are present. The elements iron, aluminium, and chromium, whose oxides are made insoluble by ignition, dissolve completely when the residue has been heated only to 120°, at any rate upon the second digestion with HNO_3 (1.20). Of the element gold, if originally present as chloride, only the small portion reduced by dust from the air is left in the residue.

6. Whenever it is directed, as at the end of this procedure, to "wash" a residue or precipitate, it is understood, unless otherwise stated, that this operation is to be continued until the washings will give no test for some substance known to be present in the solution in considerable quantity.

Procedure 6. — Support the filter containing some of the residue insoluble in HNO_3 (P. 5) in a stout platinum ring or in a funnel completely covered with paraffine. Pour through it 5–10 ccm. pure concentrated HF, collecting the liquid in the platinum dish containing the main part of the residue. Heat on a steam-bath for 5 minutes. Dilute with 25 ccm. cold water, decant the solution through the same filter, and wash the residue and the filter thoroughly. Then rinse the residue from the platinum dish into a casserole. Collect the solution in a second platinum dish. (Residue, P. 7; solution, P. 31.)

Notes. — 1. The HF dissolves silica and all the oxides of the niobium and tungsten groups, except that of tin, when this is present in large quantity; but this also dissolves on diluting the solution with cold water. All the substances specifically named in P. 5, N. 3 also pass into solution in HF, with the exceptions of ThF_4 and $Th_3(PO_4)_4$, of the Bi_2O_3 present in excess of about 6 mgm., and of some $Sn_3(PO_4)_4$ when this is present in large quantity.

2. A residue undissolved by the HF may consist of one or more of the following substances, if the original substance was non-metallic: $PbSO_4$, $BaSO_4$, $SrSO_4$; HgS, native MoS_2; MnO_2, PbO_2; ignited or native Al_2O_3, Cr_2O_3, $FeCr_2O_4$ (chromite), SnO_2, or TiO_2; AgCl; BiF_3,

ThF_4; Prussian blue; $Sn_3(PO_4)_4$, $Th_3(PO_4)_4$ (as in monazite); certain silicates (such as cyanite, andalusite, tourmaline, beryl, zircon, topaz); S, C, SiC. It may consist of one of the following substances, if the original substance was a metal: Au; Pt, Ir, Rh, Ru, or Os, or alloys of these; or certain alloys of iron (such as ferrochrome, ferrosilicon).

3. In spite of the rather numerous exceptions named in the preceding note, by far the larger proportion of substances ordinarily submitted to analysis, including almost all silicates, are decomposed by treatment according to the foregoing procedures.

Procedure 7. — Add to the residue insoluble in HF (P. 6) 15 ccm. HCl (1.20), and boil gently for 5 minutes. Then add slowly 10 ccm. water, keeping the liquid at its boiling-point. Decant while still hot through the filter previously used, if this contains any of the residue. [If it is doubtful whether the HCl has dissolved anything, evaporate the solution to dryness to determine it.] If the residue has been dissolved to a considerable extent, but not completely, boil it with successive portions of HCl (1.20) as long as a considerable quantity of substance is dissolved, diluting and decanting each time as before. To the residue add 3 ccm. HNO_3 (1.42) and 10 ccm. HCl (1.20), and heat on a water-bath for 5 minutes, or longer if an action is taking place. Dilute with an equal volume of water, filter through the same filter-paper, and wash the residue. Unite the HCl and aqua regia solutions. Separate the residue from the filter, or incinerate the latter, if necessary. (Residue, P. 8; solution, P. 17.)

Notes. — 1. Of the substances named in P. 6, N. 2, which may constitute the undecomposed residue, it will be found that $PbSO_4$, $SrSO_4$, MnO_2, and PbO_2 dissolve completely in 30 ccm. HCl (1.20) on 5 minutes' boiling, even when such quantity is present as contains 500 mgm. of the metallic element; and they remain in solution on the addition of 20 ccm. boiling water. The same is true of fused AgCl up to a quantity containing 100 mgm. Ag, of $BaSO_4$ up to 20 mgm., and of $Sn_3(PO_4)_4$ in large quantity.

2. By the treatment with aqua regia, HgS, Au, and Pt (except when alloyed with another platinum metal) are also completely dissolved.

3. The cases in which a subsequent fusion must be resorted to are therefore rare. The important substances for which it is necessary are named in P. 8, N. 1 and 2.

Procedure 8. — If the residue insoluble in aqua regia (P. 7) is non-metallic and light-colored, and if it is thought to consist of a sili-

cate or of $BaSO_4$, or if there is no indication as to its nature, fuse it with Na_2CO_3 as directed in P. 9.

If the residue is non-metallic and light-colored, and if it is thought to consist of a metallic oxide, fluoride, or phosphate, fuse it with $K_2S_2O_7$ as directed in P. 12.

If the residue is metallic, or if it is non-metallic and dark-colored, fuse it with Na_2O_2 as described in P. 13.

Notes. — 1. The important light-colored non-metallic substances which may occur in the residue insoluble in HF, HCl, and aqua regia are: $BaSO_4$, certain silicates, ThF_4, native or ignited Al_2O_3, TiO_2, $ZrO_2.SiO_2$, monazite, and SnO_2. By fusion with Na_2CO_3 the silicates and $BaSO_4$ are readily converted into soluble compounds, but this method is ineffective with the other substances (except possibly ThF_4). All of these, except SnO_2, dissolve in dilute H_2SO_4 after fusion with $K_2S_2O_7$. SnO_2 is best brought into solution by fusing it with 20 times its weight of a mixture of equal quantities of Na_2CO_3 and S in a porcelain crucible, extracting the mass with water, and treating the solution according to Part II, and the residue, after dissolving in hot HCl (1.12) and properly diluting, by P. 71.

2. The important substances that may constitute a dark-colored non-metallic residue are: chromite ($FeCr_2O_4$), graphite or coal (C), carborundum (SiC), molybdenite (MoS_2), and Prussian blue ($Fe_4(FeC_6N_6)_3$). A metallic residue may consist of an alloy of iron (like ferrosilicon or ferrochrome) or of a platinum metal or alloy. Most of these substances require fusion with an oxidizing flux, and all of them yield to it. The extremely powerful one, Na_2O_2, is employed so that the method may be general; for even the platinum metals, if in a moderately fine state of division, are oxidized by it. A mixture of Na_2CO_3 and KNO_3 would effect decomposition of the other substances; and, if preferred, it may be substituted for Na_2O_2, except when platinum metals are to be treated.

Procedure 9. — If its character makes fusion with Na_2CO_3 advisable (P. 8), mix the residue insoluble in aqua regia (P. 7) with ten times its weight of anhydrous Na_2CO_3 in a platinum crucible. Cover the crucible and heat it for 30 minutes either over a powerful burner (preferably within a cylindrical porcelain jacket) or over a blast-lamp, adding more Na_2CO_3 if a perfectly fluid fusion does not result. Insert in the liquid mass a stout platinum wire with a small horizontal ring at the lower end, and allow the mass to solidify completely. Then heat the crucible till the mass begins to melt around the

sides, and remove it by means of the platinum wire. Digest it on a steam-bath with 50 ccm. water till the mass is entirely disintegrated. Filter, and wash the residue. (Residue, P. 10; solution, P. 11.)

Note. — 1. If the mass is not removed from the crucible, its disintegration by the hot water is often very slow.

Procedure 10. — Heat the residue from the aqueous solution of the fused mass (P. 9) with 5 ccm. HCl (1.12) for 5 minutes, and add 25 ccm. hot water. Filter, and wash the residue. (Residue, P. 12; solution, P. 71.)

Note. — 1. Of the elements of the tungsten, niobium, selenium, and silver groups, tin and titanium are the only ones that are at all likely to be present in the HCl solution of the fusion of the residue (P. 7) insoluble in all the acids. As these elements are tested for also in connection with subsequent groups, the solution is immediately precipitated with H_2S (P. 71).

Procedure 11. — Acidify the aqueous solution of the fused mass (P. 9) with HCl, evaporate the solution to dryness, and heat the residue in a hot closet at 120° for an hour. Heat the residue with 5 ccm. HCl (1.12). Add 25 ccm. water; filter; and wash the residue. (Residue, P. 6; solution, P. 71.)

Notes. — 1. The solution of the fused mass is evaporated with HCl, and the residue heated at 120° and treated with HCl to separate silica, which is very likely to be present. A white insoluble residue probably consists of nothing but silica; but, if desired, this may be determined by warming it with HF (P. 6), and treating the solution by the subsequent procedures (P. 31).

2. Since it is very improbable that elements of the selenium and silver groups are present, owing to the fact that most, if not all, of their compounds are decomposed by the preceding treatment with various acids, the solution of the dehydrated residue is precipitated at once with H_2S.

Procedure 12. — If the character of the residue insoluble in aqua regia (P. 7) makes fusion with $K_2S_2O_7$ advisable (P. 8), or if this residue has been fused with Na_2CO_3 and undecomposed substance still remains on treating the fused mass with HCl (P. 10), pour the residue gradually into a platinum crucible containing ten times as

much $K_2S_2O_7$ in a state of fusion. Cover the crucible, and keep the temperature at a dull red heat for 20 minutes. Cool the crucible, pour into it 2–4 ccm. H_2SO_4 (1.84) and heat again, keeping the crucible covered until the whole mass becomes fluid. Cool the crucible and gradually pour its (still liquid) contents into 30 ccm. water. Decant the solution from the residue, add to this 5–10 ccm. H_2SO_4 (1.20), and heat to boiling. Filter and wash the residue. (Residue, P. 6, and if there is still a residue, treat it by P. 20.) Unite the filtrate with the previously decanted solution. Add 2 drops HCl (1.12), shake the solution vigorously for 5 minutes with 1 ccm. moist precipitated Ag, and filter. (Precipitate, reject; filtrate, P. 71.)

Notes. — 1. The 2–4 ccm. H_2SO_4 are added at the end of the fusion to save the considerable time otherwise consumed in the disintegration of the mass by water, to dissolve as far as possible rare-earth phosphates (as in monazite) which otherwise may separate in large quantity on the addition of water, and to hold titanium in solution, which it does even though the solution be boiled. Any undissolved residue is heated with H_2SO_4 (1.20) in order to dissolve these phosphates and also any double sulphates of the rare-earths (like $2K_2SO_4.Th(SO_4)_2$) which may have been precipitated in crystalline form.

2. An insoluble residue may consist of SiO_2, which is ascertained by treating it with HF (P. 6) and evaporating the solution to complete dryness after the addition of a little H_2SO_4; of alkaline-earth sulphates, which are treated by P. 20; and of undecomposed substances (such as certain silicates, cassiterite, etc.), which would be left as a residue upon boiling with Na_2CO_3 (P. 20), and which should be fused with Na_2CO_3 (P. 9) or with a mixture of Na_2CO_3 and S (P. 8, N. 1).

3. The solution is first shaken with Ag to remove the platinum which is dissolved from the crucible by the acid flux; if this is not removed a precipitate will be obtained with H_2S even though no elements of that group are present. The Ag precipitate is rejected, since it cannot contain mercury (owing to its volatility at a red heat) or gold (owing to the metal being unattacked by $K_2S_2O_7$), and is very unlikely to contain palladium or platinum (aside from that taken up from the crucible), and since these are the only elements precipitable by silver from a solution containing little HCl (see Part IV).

Procedure 13. — If its character makes fusion with Na_2O_2 advisable (P. 8), introduce the residue insoluble in aqua regia (P. 7), gradually if a violent action occurs, into a nickel crucible in which

5 gm. Na_2O_2 have been brought to a state of fusion. Heat the lower part of the crucible to dull redness, maintaining a temperature sufficient to keep the mass fluid for from 5 to 20 minutes, according to the readiness with which the residue is attacked. After cooling, place the crucible on its side in a covered casserole, add 50 ccm. cold water, and, after the violent effervescence has ceased, warm gently. Rinse out the crucible, transfer the solution and residue to a flask, and add gradually HCl (1.20) until the black residue of $Ni_3O_4.2H_2O$ dissolves, meanwhile keeping the solution cold. If complete solution does not result, decant the solution, after settling, from the residue, boil the latter with HCl (1.20), and unite the solution and any residue with the decanted solution. Transfer the mixture to a 200 ccm. distilling flask, having its side-arm bent downwards and dipping into 10 ccm. 5 % NaOH solution in an Erlenmeyer flask surrounded by a large beaker of cold water. Close the flask with a cork through which passes a straight tube reaching to the bottom. Boil the solution for 5–10 minutes, taking care that all the distillate condenses. Replace the NaOH solution containing the distillate by a fresh portion of NaOH solution, and distil again for 5 minutes. (Distillate, P. 14; residual solution, P. 15.)

Notes. — 1. Of the substances possibly present in a dark-colored or metallic residue, the platinum metals and their alloys are most difficultly attacked by Na_2O_2. They should therefore be rather finely powdered, which is usually best accomplished by pounding the substance in a diamond steel mortar. It is not necessary, however, to resort to the special methods of producing an extremely fine state of division, like fusion with lead, which have to be employed when other methods of attack, like heating with NaCl and Cl_2, are to be used. Twenty minutes' fusion is sufficient with 500 mgm. of the most resistant alloys.

2. As the nickel crucible is much attacked by the flux, the fusion should not be unduly prolonged. Silver and platinum crucibles are also strongly attacked, and have no advantage in this respect, while they have the disadvantage of being much more expensive.

3. The flux Na_2O_2 can now be obtained commercially in a fair degree of purity, being made from metallic sodium; it often contains some iron, however. Nevertheless, to determine the nature and approximate quantity of the impurities introduced from the crucible and flux into the solution to be analyzed, a blank fusion and an analysis of the fused mass should be made.

4. Upon treatment of the fused mass with water, a violent evolution of oxygen occurs, and a large quantity of a fine black precipitate consisting of $Ni_3O_4.2H_2O$ separates. This dissolves completely on the addition of HCl.

5. The products resulting from the fusion of the substances (named in P. 8, N. 2) possibly present in the residue, and treatment of the fused mass with water, are as follows: chromite, Fe_2O_3 and Na_2CrO_4; carbon, Na_2CO_3; carborundum, Na_2CO_3 and Na_2SiO_3; molybdenite, Na_2MoO_4 and Na_2SO_4; Prussian blue, Fe_2O_3 and Na_2CO_3; ferrosilicon or ferrochrome, Fe_2O_3 and Na_2SiO_3 or Na_2CrO_4; platinum, $xNa_2O.Pt_2O_3$; iridium, $xNa_2O.IrO_3$; rhodium, RhO_x (?); osmium, Na_2OsO_5 (?); ruthenium, Na_2RuO_5 (?). All of these products, except Fe_2O_3, $xNa_2O.Pt_2O_3$, $xNa_2O.IrO_3$, and RhO_x dissolve upon treating the fused mass with water. Na_2CrO_4 imparts to the solution a pure yellow color; Na_2OsO_5 a yellow-orange color; and Na_2RuO_5 a dark orange-red color. All of the products insoluble in water dissolve on the addition of HCl to the solution or on heating the residue with HCl (1.20), except a part of the $Pt_2O_3.2H_2O$ when present in large quantity. The $Pt_2O_3.2H_2O$ produced by action of the acid on $xNa_2O.Pt_2O_3$ forms a dense yellow powder, which is dissolved only slowly by hot HCl (1.20) or even aqua regia. $xNa_2O.IrO_3$ dissolves in HCl with production of a dark blue solution.

6. The solution must be kept cold during the neutralization, since otherwise osmium may be lost in the form of the very volatile OsO_4, which is formed when a Na_2OsO_5 solution is acidified. The solution must not be filtered through paper, as this immediately reduces Na_2RuO_5 with formation of a black deposit.

7. The OsO_4 (osmium tetroxide) set free when the Na_2O_2 solution is acidified distils over with great readiness (usually within two or three minutes), since in the pure state it boils not far from 100° and since it dissolves in water apparently without change. The vapor has an odor somewhat similar to that of chlorine, and is extremely irritating to the eyes and nose. The distillate assumes a yellow color when a little osmium; a dark orange color, when much osmium is present.

8. Although a similar volatile oxide of ruthenium (RuO_4) exists, it is not formed when the Na_2O_2 solution is heated with HCl; on the contrary, the Na_2RuO_5 present is reduced with formation of $RuCl_3$. Consequently no ruthenium distils over.

9. If osmium were present in the original substance in the form of one of its salts, it would be completely volatilized in the first treatment with HNO_3 (P. 1) or in the subsequent evaporation (P. 2 or 3); for all soluble osmium compounds yield OsO_4 when boiled with HNO_3. Therefore, if its presence in such a form be thought possible, the first treat-

ment of the substance with HNO_3 (1.20) should be carried out, as indicated in P. 1, in a distilling flask, the liquid boiled for 2 or 3 minutes, and the distillate collected as in this procedure and tested by P. 14. As osmium is in practice very rarely met with except in the metallic form, it is, as a general rule, unnecessary to complicate in this way the procedure for the preparation of the solution.

10. Since metallic osmium, both in the pure state and alloyed with iridium or other platinum metal, is scarcely attacked by aqua regia, unless it has been brought to an extremely fine state of division by a chemical method, there is little danger of completely dissolving and volatilizing it in the treatment with that solvent in P. 7. Still, if it is desired to determine with certainty the presence or absence of a small quantity of osmium, it is best either to heat the residue undissolved by HNO_3, HF, and HCl with the aqua regia in a distilling flask and to collect and test the distillate as in P. 13 and 14, or to fuse the residue with Na_2O_2 (as in P. 13) without treating it with aqua regia at all.

Procedure 14. — Add to the distillate (P. 13) 4–5 drops 20% $Na_2S_2O_3$ solution, acidify with HCl (1.12), keeping the liquid cool, and add to the solution one-fifth its volume of HCl (1.12). (Precipitate and solution, reject.)

Note. — 1. OsS_2 separates as a brownish-black precipitate. The test is obtained when only 0.5 mgm. Os is present in the solution submitted to distillation. It is the volatility of the osmium and its presence in the distillate that is especially characteristic — not the fact of its precipitating with $Na_2S_2O_3$; for if they could be present in the distillate, other elements, for example, ruthenium, would give a similar precipitate.

Procedure 15. — Evaporate the residual solution from the distillation (P. 13) to dryness, and heat the dry mass at 120° for an hour. Then heat it to boiling with 20 ccm. HCl (1.02). Filter, and wash the undissolved residue. (Residue, P. 16; solution, P. 71.)

Note. — 1. The solution is evaporated and the salt mass heated at 120°, so as to make insoluble the H_2SiO_3 and H_2WO_4 that may be present. PtO_2 may also be present in the residue undissolved by the HCl (1.02); see P. 13, N. 5.

Procedure 16. — Treat the residue (P. 15) just as described in P. 6. (Solution in HF, P. 31.) Add any residue undissolved by

HF to the HCl solution (P. 15), and treat the mixture by P. 71, allowing the cold solution saturated with H_2S to stand an hour or more before filtering.

Notes. — 1. Of the elements of the tungsten and niobium groups, only tungsten and titanium are at all likely to be present in this HF solution; for tin and antimony, even if present in the fused residue, would dissolve on treating the dehydrated residue with HCl (P. 15), and niobium and tantalum are not met with at all in alloys nor in compounds insoluble in HF. Hence, the procedure given for those groups may be shortened in its application to this HF solution, by the omission of those operations which serve only to remove and detect the elements almost certainly absent; or this HF solution may be united with the first HF solution obtained when the original dehydrated residue was treated with HF (P. 6).

2. The residue insoluble in HF, if of a yellow color, may consist of Pt_2O_3. It is added to the solution about to be precipitated with H_2S, because the reagent converts the Pt_2O_3 into Pt_2S_3, which dissolves when the H_2S precipitate is subsequently treated with aqua regia.

Procedure 17. — Evaporate the mixed HCl and aqua regia solutions of the residue insoluble in HNO_3 and HF (P. 7) just to dryness. Heat the residue to boiling with 10 ccm. HCl (1.02), cool, and after 2–3 minutes filter. Wash the undissolved residue thoroughly with as little HCl (1.02) as possible, adding the washings to the filtrate. (Precipitate, P. 18; filtrate, P. 71.)

Note. — 1. The residue undissolved by the HCl (1.02) may consist of AgCl, $PbCl_2$, $PbSO_4$, $BaSO_4$, and $SrSO_4$, which, though soluble in hot concentrated HCl, are only slightly dissolved by a small quantity of cold HCl (1.02). The solution may contain the other substances named in P. 7, N. 1 and 2, especially lead, manganese, mercury, gold, and the platinum metals. It is therefore united with the main solution and submitted to the regular scheme of analysis, beginning with the H_2S precipitation (P. 71).

Procedure 18. — Pour repeatedly through the filter containing the residue insoluble in dilute HCl (P. 17) a 10–15 ccm. portion of cold NH_4OH (0.90). Filter and wash the residue with NH_4OH (0.96). (Residue, P. 19.) Acidify the filtrate with HNO_3. (Precipitate and solution, reject.)

Note. — 1. The residue is treated with NH_4OH to extract any AgCl present. Cold NH_4OH is used, since $PbSO_4$ is somewhat soluble in hot NH_4OH. The filtrate is acidified to determine whether any silver is present. The AgCl dissolves in the NH_4OH, owing to the formation of a salt with a complex cathion, $Ag(NH_3)_2{\cdot}Cl'$.

Procedure 19. — Pour repeatedly through the filter containing the residue undissolved by the NH_4OH (P.18) a 10–20 ccm. portion of hot 25 % $NH_4C_2H_3O_2$ solution to which 5 % NH_4OH have been added. Filter and wash the residue with the $NH_4C_2H_3O_2$ solution until it is free from lead. (Residue, P. 20.) Acidify the filtrate with $HC_2H_3O_2$, and add a few drops of a 10 % K_2CrO_4 solution. (Precipitate and solution, reject.)

Note. — 1. The residue is treated with $NH_4C_2H_3O_2$ to extract any $PbSO_4$ or PbO_2H_2 present. Even 500 mgm. Pb as $PbSO_4$ dissolve in 15 ccm. boiling $NH_4C_2H_3O_2$ solution. $BaSO_4$ is not appreciably soluble. A small quantity of $SrSO_4$ dissolves, but this does not precipitate with K_2CrO_4 in the confirmatory test for lead. Even if all the $SrSO_4$ present in the residue passes into the NH_4OH solution, there is no danger of failing to detect strontium as a constituent of the original substance; for $SrSO_4$ is so soluble in dilute HNO_3 (P. 5) and dilute HCl (P. 17) that a considerable quantity of it will be found in the main solution; thus 10 ccm. of cold HCl (1.04) or of cold HNO_3 (1.032) saturated with $SrSO_4$ contain about 10 mgm. Sr.

Procedure 20. — Unite the residue insoluble in $NH_4C_2H_3O_2$ solution (P. 19) with the residue from the $K_2S_2O_7$ fusion (P. 12) after its treatment with HF. Transfer these, with the filters if necessary, to a casserole, add 10 ccm. saturated Na_2CO_3 solution, and boil gently for 10 minutes, replacing the water which evaporates. Dilute with an equal volume of water, and filter. (Filtrate, reject.) Wash the residue thoroughly, and pour repeatedly through the filter containing it a 10 ccm. portion of hot HCl (1.02). (Solution, P. 71.)

Notes. — 1. Even 500 mgm. Sr as $SrSO_4$ are completely converted to $SrCO_3$ by this procedure. An equal quantity of $BaSO_4$ would require boiling with two or three successive portions of Na_2CO_3 solution, but as the quantity of $BaSO_4$ that can be present in this residue cannot be very large, owing to its rather small solubility in HCl (1.20) (see P. 7, N. 1), a single boiling suffices.

2. The Mass-Action Law requires that the difficultly soluble sulphate be transformed into carbonate until the ratio (C_{SO_4}/C_{CO_3}) of the concentrations of the SO_4 and CO_3 ions in the solution becomes equal to the ratio (SP_{MSO_4}/SP_{MCO_3}) of the solubility-products of the sulphate and carbonate in pure water. Now since the second ratio, according to recent solubility determinations, has (at 18°) a value larger than 60 in the case of the two strontium salts, a very large amount of $SrSO_4$ would have to be transformed to Na_2SO_4 before the ratio C_{SO_4}/C_{CO_3} attained this value. On the other hand, in the case of the two barium salts, the second ratio has apparently the value 0.25 (since it is found that the conversion ceases when $C_{SO_4}/C_{CO_3} = 0.25$), so that after a certain amount of $BaSO_4$ has been transformed, the reaction ceases. Aside from this great difference in the equilibrium-ratios, the rate of transformation is doubtless much less in the case of the $BaSO_4$, owing to its very slight solubility. It is to increase this that the solution is boiled.

Confirmatory Experiments and References.

P. 1, N. 4. — The following minerals or products left a large residue when one gram was treated with HNO_3 (1.20) as above described: Galenite (PbS), emery (Al_2O_3), chromite ($FeCr_2O_4$), zircon ($ZrSiO_4$), pyrolusite (MnO_2), lead dioxide (PbO_2), cinnabar (HgS), fluorite (CaF_2), fused silver chloride (AgCl), and Prussian blue ($Fe_4(FeC_6N_6)_3$). One gram of fused $PbCrO_4$ dissolved on three successive digestions with 20 ccm. HNO_3 (1.20). One gram of precipitated $CaSO_4$ dissolved upon one treatment with 10 ccm. HNO_3 (1.20), after diluting with 20 ccm. water, and remained in solution upon cooling.

P. 3, N. 1. — In several experiments 500 mgm. Pb as $Pb(NO_3)_2$ were treated with 5 ccm. commercial HF containing some H_2SO_4. The mixture was then treated according to P. 3 and P. 5. A residue consisting of $PbSO_4$ always remained, as was proved by decomposing it with Na_2CO_3 and testing for its constituents.

3 ccm. pure 43% HF solution were mixed with 10 ccm. HCl (1.03) in one experiment and with 20 ccm. HCl (1.02) in another; then 1 ccm. 10% $BaCl_2.2H_2O$ solution was added; no precipitate (of BaF_2) separated even on standing 10 minutes. One drop (0.04 ccm.) H_2SO_4 (1.20) was then added: a precipitate formed immediately.

P. 3, N. 3. — To 5 ccm. portions of 43% HF solution 1% solutions of various elements were gradually added until a permanent precipitate was produced, waiting 2 or 3 minutes after the addition of each half milligram or milligram. The number of milligrams that had to be added were as follows: Li, 5; Mg, 2; Ca, 0.5; Sr, 8; Ba, 30; Pb, 0.5; Bi, 0.5; Th, 0.5; Ce, 0.5; Pr, 0.5; Nd, 0.5; La, 0.5; Y, 0.5; and Er, 0.5.

P. 3, N. 4. — 2 mgm. Ta as Ta_2O_5 were heated for 15 minutes on the water-bath with 5 ccm. 43% HF solution, and the solution was then evaporated to complete dryness, in one experiment twice with the addition of 2 ccm. HNO_3 (1.42), and in another, once without this addition. The residues were then tested for tantalum by the KHF_2 test as described in Part II. In the experiment in which the HNO_3 was added, a satisfactory test was obtained; in the other experiment, no test whatever was obtained, showing that the 2 mgm. Ta were completely volatilized in the latter case. 1 mgm. Ti as H_2TiO_3 was dissolved in 5 ccm. HF, and the solution was then evaporated to complete dryness, in one case twice with the addition of 2 ccm. HNO_3 (1.42), in another once without that addition. The residues were treated with 20 ccm. H_2O_2 and 2 ccm. HCl. No color was obtained in the former experiment; a color corresponding to at least 0.5 mgm. in the latter.

A mixture of 1 mgm. Se, 1 mgm. As, 1 mgm. Hg, and 1 mgm. Sb was evaporated to dryness with HNO_3 and treated according to P. 3 (without the addition of SiO_2) and subsequent procedures until the final tests for these four elements were reached. Very satisfactory tests for all of them were obtained, showing they were not volatilized in the HF evaporation.

About 40 mgm. GeO_2, made by heating the metal with HNO_3 (1.20) till it was dissolved, evaporating the solution to dryness, and heating the residue at 120° in a platinum dish to a constant weight, were treated with 5 ccm. HF and 5 ccm. HNO_3 (1.42); the solution was then evaporated to dryness and the residue heated to 120° and weighed: the change in weight was only 0.1 mgm.

P. 3, N. 5. — 100 mgm. Ta as Ta_2O_5 were dissolved in 5 ccm. HF and evaporated to dryness three times with 3 ccm. HNO_3 (1.42); the residue was then boiled with 15 ccm. HNO_3 (1.05) for 1 minute: the solution after filtration, neutralization with NH_4OH, and addition of $HC_2H_3O_2$ and $CaCl_2$ gave no precipitate, showing the absence of HF.

The same experiment was repeated with 100 mgm. Nb as Nb_2O_5 and with 100 mgm. Ti as H_2TiO_3 with just the same result.

P. 3, N. 6. — 50 mgm Ca as $Ca(NO_3)_2$ were digested on a water-bath 15 minutes with 5 ccm. HF; 5 ccm. HNO_3 (1.42) were added, and the solution was evaporated to complete dryness; the residue was covered with HNO_3 (1.42) and this was evaporated off; 10 ccm. HNO_3 (1.05) were then added; and the solution was made alkaline with NH_4OH: only a very slight turbidity resulted.

The same experiment was repeated several times with 200 and 500 mgm. Ca: in every case, a residue remained or a milky colloidal solution resulted upon treatment with HNO_3 (1.05).

500 mgm. Pb as $Pb(NO_3)_2$ and 500 mgm. Bi as $Bi(NO_3)_3$ were treated in separate experiments, in the manner just described: a perfectly clear solution was produced on adding the 10 ccm. HNO_3 (1.05).

A mixture of 250 mgm. Mg, 250 mgm. Ba, 250 mgm. Sr, and 250 mgm. Li was treated in the same manner; a perfectly clear solution resulted on the addition of the HNO_3 (1.05), and this gave no precipitate on neutralizing with NH_4OH and adding $HC_2H_3O_2$ and $CaCl_2$.

P. 3, N. 7. — In regard to the solubility in HF of the oxides of the tungsten and niobium groups, see C. E. on P. 6, N. 1.

P. 3, N. 8. — 500 mgm. Ca, as $Ca(NO_3)_2$, were treated according to P. 3 with addition of SiO_2, and then by P. 5 and 6: no residue whatever remained after the final treatment with HF. This experiment was repeated many times with the same result.

250 mgm. Y, 250 mgm. Ce, 500 mgm. Nd, a mixture of 50 mgm. Er and 50 mgm. Y, and a mixture of 500 mgm. Nd and 500 mgm. La (all as nitrates) were treated in separate experiments according to P. 3, 5, and 6: in all of these cases there was no residue or only a very small one (of 2–3 mgm.) after the final treatment with HF.

Portions of 250 mgm. Th, and of 50 mgm. Th, as $Th(NO_3)_4$, were treated according to P. 3, 5, and 6: on treatment with HF a dense crystalline residue estimated at one-tenth the original amount remained. This experiment was repeated many times with the same result.

P. 3, N. 11. — 100 mgm. Ta, as Ta_2O_5, were dissolved in 5 ccm. HF and evaporated to dryness three times with 3 ccm. HNO_3 (1.42); the residue was then boiled with 15 ccm. HNO_3 (1.05) for 1 minute: after filtration the solution gave a heavy precipitate with NH_4OH. The experiment was repeated with the modification that the residue was heated at 120° for 70 minutes after the three evaporations; the HNO_3 (1.05) solution then gave no precipitate whatever with NH_4OH. This shows that dehydration is necessary and sufficient to make the Ta_2O_5 insoluble.

The same experiment was twice made with 500 mgm. Sn: the HNO_3 solution of the residue which was not dehydrated gave a large precipitate with NH_4OH, and with H_2S (after evaporation with HCl).

P. 5, N. 1. — A series of experiments was made in which solutions of various elements were evaporated to dryness with HNO_3, and the residues were heated in a hot closet for one hour, and then boiled gently with 5 ccm. HNO_3 (1.20) for 5 minutes; the solutions thus obtained were diluted with 15 ccm. water, heated to boiling, filtered, and evaporated to dryness in crucibles, which were then gently ignited and weighed. It was found in this way that from a residue of 30 mgm. Sn, as H_2SnO_3, only 0.3 mgm. dissolved; from one of 70 mgm. W, as H_2WO_4, only 1.1 mgm. dissolved, which was proved to be not tungsten, but some impurity, by its complete insolubility in NH_4OH; from a residue of 56 mgm. Ta, as TaO_5H_5, only 0.4 mgm. dissolved; from one of 100 mgm. Nb a few milligrams dissolved, but on adding NH_4OH to the solution a precipitate formed which dissolved completely in

dilute HCl, proving that no niobium dissolved in the HNO_3; from a residue of 22 mgm. Sb, as Sb_2O_5, 1 mgm. Sb dissolved on the first treatment with HNO_3, and 0.9 mgm. on each of the two following treatments; and from a residue of 85 mgm. Ti, as H_2TiO_3, .8 mgm. dissolved.

750 mgm. metallic Sn were treated with HNO_3 (1.42), the acid was evaporated off, and the residue heated at 120° for an hour. The residue was then heated for ten minutes with 5 ccm. HNO_3 (1.20), 20 ccm. water added, the solution heated to boiling, and filtered. The filtrate was evaporated with HCl, and tested for tin by means of the $HgCl_2$ test. No tin was found to be present.

A mixture of 1 mgm. Ti, 1 mgm. Ta, 1 mgm. Nb, 1 mgm. W, 1 mgm. Sn, and 1 mgm. Sb was treated according to P. 3, 5, and 6, and the subsequent procedures (Part II) for the analysis of the tungsten and niobium groups. Distinct tests were obtained for all the elements except antimony, showing that their oxides remained in the residue insoluble in HNO_3. (See also T. A., Part II.)

2 mgm. Sb, as dehydrated Sb_2O_5, did not dissolve in 5 ccm. boiling HNO_3 (1.20); but it nearly disappeared upon adding 20 ccm. water and boiling. 5 mgm. Sb, as Sb_2O_5, treated in this way did not dissolve; but almost all of it dissolved upon a second treatment. 10 mgm. Sb left a large residue even after two treatments.

50 mgm. W, as Na_2WO_4, and 150 mgm. PO_4, as Na_2HPO_4, were evaporated with HNO_3 and heated at 120° for two hours; upon adding HNO_3 (1.20), and diluting, everything dissolved.

The same procedure was followed with a mixture of 5 mgm. W, as Na_2WO_4, and 50 mgm. As, as Na_3AsO_4, with the same result.

10 mgm. W were precipitated as H_2WO_4 out of a Na_2WO_4 solution by boiling with HNO_3, and to the mixture 1 ccm. saturated $H_2C_4H_4O_6$ solution was added: the precipitate immediately dissolved.

50 mgm. Sb, as Sb_2O_5, after dehydration at 120° were treated in one experiment with 10 ccm. half-saturated citric acid solution, and in another experiment with 10 ccm. of a mixture of commercial lactic acid with its own volume of water; upon warming, the residue dissolved.

To 1 mgm. W, 1 mgm. Nb, 1 mgm. Ta, 1 mgm. Sn, 20 mgm. Sb (in separate experiments) in solution in 3–5 ccm. HF, 250 mgm. H_3BO_3 and 5 ccm. HNO_3 (1.42) were added. The solution was evaporated to dryness, and the residue treated with HNO_3 (1.20), which was then diluted with water. In each case, a small residue of the metallic oxide remained, and this did not go into solution on the addition of 500 mgm. more H_3BO_3.

To 1 gram H_3BO_3, 5 ccm. HF and 5 ccm. HNO_3 (1.42) were added, and the solution was evaporated to dryness on a water-bath; no residue was left.

A mixture of 500 mgm. Ti, as TiO_2, and 500 mgm. Zr, as $Zr(NO_3)_4$, was

dissolved in HF and evaporated to complete dryness four times. It was then heated at 120° for two hours. The residue was treated twice with HNO_3 and water according to the procedure. On the second treatment it went almost entirely into solution, showing that zirconium causes even large quantities of titanium to dissolve.

P. 5, N. 3. — 500 mgm. Mo, as MoO_3, were dissolved in HF, and following P. 3, the solution was evaporated three times with HNO_3 (1.42) and heated at 120° for an hour. The residue was twice heated with 5 ccm. HNO_3 (1.20), which was afterwards diluted with 20 ccm. water. After the two treatments about one-third of the molybdenum remained undissolved.

The experiment was repeated with 100 mgm. Mo. A fairly large residue remained after the first treatment of the dehydrated residue with HNO_3, but only a very small one (2–3 mgm.) after the second treatment.

In regard to Mo in presence of W or Sn, see T. A., Part II.

A mixture of 200 mgm. metallic Sb and 50 mgm. Bi, as $Bi(NO_3)_3$, was treated with HNO_3 (1.20), evaporated to dryness, and heated at 120°. The residue was heated 10 minutes with 5 ccm. HNO_3 (1.20), 20 ccm. water were added, and the mixture was heated to boiling and filtered. The residue was washed thoroughly with hot water and dissolved in HCl (1.20). To the solution NH_4OH and $(NH_4)_2S$ were added. Complete solution took place.

The experiment was repeated with a mixture of 500 mgm. Sb and 500 mgm. Bi. Even though the dehydrated residue was twice treated with HNO_3, and thoroughly washed with HNO_3 (1.05), a large black precipitate of Bi_2S_3 remained after adding NH_4OH and $(NH_4)_2S$ to the HCl solution of the HNO_3 residue.

A mixture of 50 mgm. Se, as SeO_2, and 200 mgm. Sb, as $SbCl_3$, was evaporated three times with HNO_3 and the residue heated at 120°. It was then treated with HNO_3 and water in the usual manner, and thoroughly washed with water. The undissolved residue was treated with HF, HCl, and H_2SO_3. The black precipitate which separated was boiled with HNO_3, the solution distilled with HBr, and the distillate treated with H_2SO_3. A red precipitate of Se, amounting to perhaps 5 mgm., separated.

In regard to ThF_4, see C. E. on P. 3, N. 8.

GeO_2 was made by heating the metal with HNO_3 (1.42), evaporating with HF and then with HNO_3, and dehydrating at 120°; the residue, which then weighed 110 mgm., was boiled 1 minute with 5 ccm. HNO_3 (1.20), then 20 ccm. water were added, the mixture was boiled again and filtered, and the filtrate was evaporated and the residue heated at 120° and weighed; it weighed 89 mgm, showing that 21 mgm. had dissolved. This residue of 89 mgm. was then treated again in the same manner; this time 28.5 mgm. dissolved.

50 mgm. Se, as SeO_2, and 200 mgm. metallic Sn were treated in the same manner, except that the residue insoluble in HNO_3 was dissolved in HBr, the

solution distilled and the distillate treated with H_2SO_3 and KI; a large red precipitate of Se (of perhaps 10 mgm.) was obtained.

50 mgm. Te, as TeO_2, with 200 mgm. metallic Sn in one experiment and with 200 mgm. Sb, as $SbCl_3$, in another, were treated in the same manner, except that the residue insoluble in HNO_3 was dissolved in HF, the solution evaporated with HCl and treated with H_2SO_3; a large black precipitate of Te formed in each case.

In regard to Se and Te in presence of elements of the tungsten and niobium groups, see also T. A., Part II.

50 mgm. Zr, as $Zr(NO_3)_4$, with 600 mgm. PO_4, as Na_2HPO_4, in one experiment and with 800 mgm. As, as As_2O_3, in another, were evaporated with HNO_3 and the residue heated at 120°. On treatment with HNO_3 (1.20) and dilution, a large residue remained and the solution gave a large precipitate with NH_4OH, showing that the zirconium divided itself between the two.

The experiment was repeated with a mixture of 500 mgm. Zr and 50 mgm. As: scarcely any residue remained after the treatment with HNO_3.

The last experiment was repeated, substituting 500 mgm. Ti dissolved in HF for the 500 mgm. Zr. The HNO_3 extract of the residue, after evaporation with 1 ccm. H_2SO_4, gave, upon addition of one-fifth its volume of HCl (1.12) and saturation for one hour at the boiling temperature, a considerable precipitate of As_2S_5. The residue after similar treatment also yielded a precipitate of As_2S_5 which was somewhat smaller than that obtained from the solution, showing that arsenic divides itself between the residue and solution when titanium is present.

250 mgm. Th, as $Th(NO_3)_4$, and 250 mgm. PO_4, as Na_2HPO_4, were evaporated with HNO_3 and heated at 120° for two hours. On heating on a water-bath with 10 ccm. HNO_3 (1.20), everything dissolved except a few hard particles. On adding 20 ccm. cold water a large flocculent precipitate formed, and upon then heating on the steam-bath the solution gelatinized.

50 mgm. V (as $(NH_4)_3VO_4$) and 500 mgm. Sn (as $SnCl_2$) were evaporated repeatedly with HNO_3, and the residue was heated at 120° and then treated with HNO_3 (1.20). A bright yellow residue remained, which upon treatment with HCl (1.20) yielded a blue-green solution; and the HNO_3 solution was of a brown color; thus showing that the vanadium was divided.

P. 5, N. 4. — See C. E. on P. 3, N. 3, and T. A., Part II.

P. 5, N. 5. — 500 mgm. Zr, Th, Te, Bi, Al, Cr, Pb and 75 mgm. Ga, as nitrates, were, in separate experiments, evaporated to dryness with HNO_3, and the residue heated for an hour at 120°; this was then heated with 5 ccm. HNO_3 (1.20) and finally with 20 ccm. water: everything dissolved in this single treatment; the gallium did not do so, however, until the 20 ccm. water were added. The experiment was repeated with 500 mgm. V, as $(NH_4)_3VO_4$, dissolved in HF, and with 500 mgm. Fe, as $FeCl_3$: two treatments of the

dehydrated residue with HNO_3 and water were necessary and sufficient to produce complete solution.

A mixture of 500 mgm. Ti, as TiO_2, and 500 mgm. Zr, as $Zr(NO_3)_4$, was dissolved in HCl, and the mixture evaporated three times with the addition of HNO_3 (1.42), and then heated at 120° for two hours. The residue was treated twice according to the procedure with HNO_3 (1.20) and water, and the residue still remaining was dissolved in HF, the solution evaporated with 1 ccm. H_2SO_4 (1.84), and then diluted with 100 ccm. H_2O_2, and 1 ccm. Na_2HPO_4 was added. No precipitate of $Zr_3(PO_4)_4$ separated on 20 minutes' standing.

A mixture of 50 mgm. each of Al, Ni, V, Cr, Be, and Zr was treated in the manner just described: everything dissolved on the first treatment with HNO_3.

The C. E. on P. 3, N. 8, made with the rare-earth elements other than thorium, show that even large quantities of these dissolve completely upon the treatment with the HNO_3.

20 mgm. Au, as $AuCl_3$, were four times evaporated with a little HNO_3 (1.42) and then heated at 120° for two hours. On heating with 5 ccm. HNO_3 (1.20), all but 2–3 mgm., consisting of a metallic powder, dissolved.

P. 6, N. 1. — 500 mgm. Sn, as metal, of Sb, as metal, of W, as Na_2WO_4, of Ti, as TiO_2, of Mo, as MoO_3, of Te, as TeO_2, and 30 mgm. Ge, as GeO_2, were treated in separate experiments with HNO_3, the liquid evaporated off, the residue heated at 120° for an hour or more and then heated on a steam-bath for 5 minutes with 5–10 ccm. HF: a clear or slightly opalescent solution resulted in every case except that of tin. 20 ccm. cold water were then added to each solution: the tin solution became clear, and all the others remained so.

To 5 ccm. HF, diluted with 25 ccm. cold water, a 1% Bi solution was added, 1 mgm. Bi at a time, until a permanent precipitate formed: 6 mgm. Bi were required.

To a HF solution of 500 mgm. Sn, as SnO_3H_2, 400 mgm. PO_4, as Na_2HPO_4, were added, the mixture evaporated to dryness three times with HNO_3, and the residue heated an hour at 120°; then it was heated with 5 ccm. HF, and finally 20 ccm. water were added: a large residue of at least 100 mgm. remained, and this did not dissolve on a second treatment with HF and water.

See also C. E. on P. 6, N. 3, in those cases where the minerals contain the elements of the tungsten and niobium groups.

P. 6, N. 2. — One gram of each of the following substances was treated according to P. 1, 3, 5, and 6, with the result that a large residue was left on the final treatment with HF: galenite (PbS), cinnabar (HgS), molybdenite (MoS_2), pyrolusite (MnO_2), lead dioxide (PbO_2), emery (Al_2O_3), chromite ($FeCr_2O_4$), cassiterite (SnO_2), rutile (TiO_2), fused silver chloride (AgCl), cy-

anite (Al_2SiO_5), tourmaline (Al_2O_3, (Fe, Mn, Mg)O, (K, Na, Li)$_2$O, B_2O_3, SiO_2, F), beryl ($Be_3Al_2Si_6O_{18}$), zircon ($ZrSiO_4$), monazite ((Ca, La, Pr)$_{15}$-$(PO_4)_{10}Th_2P_2O_9$).

That andalusite and cyanite (Al_2SiO_5) and tourmaline are not decomposed by HF is stated by Jannasch in his *Gewichtsanalyse*, 231, 233 (1897).

P. 6, N. 3. — One gram of each of the following substances in the form of an impalpable powder was treated according to P. 1, 3, 5 and 6, with the result that no residue, or only a very small one amounting to 1–5 mgm., was left on the final treatment with HF: magnetite (Fe_3O_4), menaccanite ($FeTiO_3$, Fe_2O_3), pyrite (FeS_2), pyrrhotite (Fe_7S_8), chalcopyrite ($CuFeS_2$), stibnite (Sb_2S_3), niccolite (NiAs), fluorite (CaF_2), cryolite (Na_3AlF_6), gypsum ($CaSO_4$), wollastonite ($CaSiO_3$), tremolite ((Ca, Mg)SiO_3), titanite ($CaTiSiO_5$), orthoclase ($K_2Al_2Si_6O_{16}$), labradorite ((Ca, Na_2) $Al_2Si_3O_{10}$), garnet ((Ca, Mg, Mn, Fe)$_3Al_2Si_3O_{12}$), gadolinite ((Y, Ce, Be, Fe)$_3SiO_5$), scheelite ($CaWO_4$), columbite (Fe(Nb, Ta)$_2O_6$), samarskite ((Fe, Y, VO_2)$_5$ (Nb, Ta)$_4O_{15}$), and the rocks basalt, obsidian, amphibole, and lava.

P. 7, N. 1. — To 500 mgm. Pb, as $PbSO_4$, successive portions of 5 ccm. HCl (1.20) were added, the solution being boiled after each addition, until the solid all went into solution: 30 ccm. sufficed to produce this result. 90 ccm. water were then gradually added, keeping the solution at the boiling point: no precipitate was produced. 800 mgm. Pb, as PbO_2, dissolved readily in 30 ccm. HCl (1.20) and remained in solution on adding 90 ccm. water.

To 20 mgm. $BaSO_4$ 30 ccm. HCl (1.20) were added and the liquid boiled a few minutes: complete solution resulted. 30 ccm. water were added to the solution kept at the boiling point: no precipitate formed.

The same experiment was repeated with 100 mgm. AgCl with the same result.

500 mgm. fused AgCl in the form of shavings were boiled for 3 or 4 minutes with successive 30 ccm. portions of HCl (1.20): the solid all dissolved on the third treatment or in 90 ccm. HCl (1.20).

500 mgm. Sn, as metal, and 400 mgm. PO_4, as Na_2HPO_4, were evaporated with HNO_3 (1.42) and heated at 120°; the residue was treated twice with HF and water, as described in P. 6, and the large residue still remaining (amounting apparently to 200 mgm.) was heated on a steam-bath for 10 minutes with 15 ccm. HCl (1.20): complete solution occurred.

P. 7, N. 3. — The following substances, in the form of a fine powder, were submitted, if non-metallic, in quantity of 1 gm. to P. 1, 3, 5, 6, and 7; if metallic, in quantity of 0.5 gm. to P. 4, 5, 6, and 7, with the result that a large residue, amounting to at least one-half of the original substance, remained in every case: molybdenite (MoS_2), emery (Al_2O_3), chromite ($FeCr_2O_4$), cassiterite (SnO_2), rutile (TiO_2), thorium fluoride (ThF_4), Prussian blue ($Fe_4(FeC_6N_6)_3$), cyanite (Al_2SiO_5), tourmaline, zircon ($ZrSiO_4$), monazite

(mainly $Th_3(PO_4)_4$), metallic rhodium (Rh), metallic iridium (Ir), Ural Mts. platinum ore (Pt, Pd, Os, Ir), Ural Mts. osmium-iridium (Os, Ir), crude ruthenium (Ru), ferrochrome (Cr, Fe), ferrosilicon (Fe with 13% Si).

P. 8, N. 1. — Barium sulphate, tourmaline, cyanite, and allied silicates are analyzed quantitatively by decomposition with Na_2CO_3. See Classen, Quantitative Analysis, Harriman's translation, p. 62, 204.

330 mgm. of cyanite, constituting the residue left after treatment of 1 gm. of the mineral by P. 1, 3, 5, and 6, were fused with 7 gm. Na_2CO_3 (this large quantity being necessary to produce a fluid fusion); on treatment first with hot water, and then with HCl, everything dissolved.

One gram of each of the following substances as an impalpable powder was treated by P. 1, 3, 5, 6, and 7, and the residue was fused with Na_2CO_3 as directed in P. 9: emery (Al_2O_3), rutile (TiO_2), cassiterite (SnO_2), monazite ($Th_3(PO_4)_4$, etc.), and zircon ($ZrSiO_4$). A large residue was left upon extracting the fusion with water and adding HCl to the residue (P. 10, 11).

The residues undecomposed by Na_2CO_3, obtained in the preceding experiment, were fused with $K_2S_2O_7$ by P. 12: emery, rutile, zircon, and monazite went completely into solution on adding the fusion to water, or upon treating the residue with H_2SO_4 (1.20). In the case of cassiterite, a large residue (450 mgm.) was left undissolved.

P. 8, N. 2. — 500 mgm. of each of the following substances, reduced to a fine but far from impalpable powder, were first treated for from 10 to 30 minutes with strong aqua regia, and the residues were then introduced into a nickel crucible containing 5 gm. Na_2O_2 in a state of fusion, and the fusion was maintained for from 5 to 20 minutes: molybdenite (MoS_2), carborundum (SiC), ferrosilicon (Fe with 13% Si), ferrochrome (Fe xCr), Ural Mts. platinum ore, Ural Mts. osmium-iridium, pure metallic iridium, crude metallic ruthenium, and (100 mgm.) pure metallic rhodium. All of these substances except the platinum metals reacted violently with the Na_2O_2, with the production of much light and heat. Complete solution resulted in case of all the substances upon adding to the fused mass 75 ccm. water, neutralizing with HCl, adding a moderate excess of it and heating (except that in case of carborundum a small flocculent precipitate of SiO_4H_4 separated).

P. 12, N. 1. — One gram monazite was treated with HF and HNO_3 (P. 2 and 5), and the residue was fused with $K_2S_2O_7$ and H_2SO_4 (P. 12). On adding the mass to water, a flocculent precipitate formed; but this dissolved on decanting the liquid and adding 10 ccm. H_2SO_4 (1.20).

500 mgm. Ti, as TiO_2, were fused with 5 gm. $K_2S_2O_7$ and 4 ccm. H_2SO_4 were added. On adding the mass to 50 ccm. water everything dissolved, and remained in solution upon boiling.

10 gm. $K_2S_2O_7$ were heated at a dull red heat in a covered platinum crucible for 20 minutes. The mass was cooled, 2 ccm. H_2SO_4 (1.84) were

added, and the mixture heated for 15 minutes below its boiling point till a clear fusion resulted. On cooling, about half the mass separated as a compact solid and the other half remained viscous. On adding 2 ccm. more of H_2SO_4 (1.84), reheating for 10 minutes till a clear fusion was obtained, and then cooling, the mass became viscous, but was so liquid that it could be poured out.

P. 12, N. 3. — The liquid mass obtained in the last experiment was added to 30 ccm. water, two drops HCl (1.20) added, and the solution was then shaken with 1 ccm. Ag. From the color of the precipitate it was estimated by comparison with the colors obtained with known amounts of platinum, that 2 mgm. Pt had been taken up from the crucible.

P. 13, N. 1. — See C. E. on P. 8, N. 2, in regard to action of Na_2O_2 on the substances that may be present in a dark-colored or metallic residue.

P. 13, N. 2. — 5 gm. Na_2O_2 were fused at a lower red heat for 20 minutes in a 35 ccm. nickel crucible weighing 17 gm. The crucible, after washing out and drying, had lost 1.0 gm.

2 gm. Na_2O_2 were fused for 20 minutes on a silver crucible cover: the cover lost 0.9 gm.

In regard to the action of Na_2O_2 on Ni, Fe, Ag, and Pt, see also Dudley, *Am. Chem. J.*, **28**, 59–66 (1902), and Leidié and Quennessen, *Bull. soc. chim.* (3) **27**, 179–183 (1902).

P. 13, N. 3. — 5 gm. Na_2O_2 from Roessler and Hasslacher, N. Y., made from metallic sodium under the Castner patent, was submitted to a qualitative analysis. This quantity contained only about 3 mgm. Fe and 1 mgm. Sb as metallic impurities.

P. 13, N. 4. — For the composition of the hydrated oxide of nickel produced, see Dudley, *J. Am. Chem. Soc.*, **18**, 901–902 (1896).

P. 13, N. 5. — For the composition of the fusion-products of platinum, see Dudley, *Am. Chem. J.*, **28**, 59–66 (1902); of iridium, Claus, *J. prakt. Chem.*, **39**, 101 (1846).

500 mgm. Ir, as metal, and 500 mgm. Pt, as metal, were in separate experiments fused in a nickel crucible with 5 gm. Na_2O_2 for 75 minutes. The fused mass was treated with 100 ccm. water, and the coal-black residue allowed to settle. The very slightly yellowish solution was decanted, acidified with HCl, and evaporated nearly to dryness; the residue was treated with HCl (1.20); the solution was decanted from the pure white NaCl and evaporated to dryness with HNO_3; the residue was dissolved in 1 ccm. water, and the solution was saturated with NH_4Cl. In the case of the iridium, only about ½ mgm. Ir separated as a black precipitate, showing that the fusion-product was almost insoluble in water. This is in disagreement with the statement of Leidié and Quennessen, *Bull. soc. chim.* (3), **27**, 181 (1902), according to which the iridium after fusion dissolves completely in water with production

of a deep blue solution. In the case of the platinum, no $(NH_4)_2PtCl_6$ was obtained. The residue insoluble in water was thoroughly washed, and it was then warmed with HCl (1.20). In the case of the iridium it very quickly dissolved to a clear dark blue solution, which during evaporation changed to a dark red color, In the case of platinum, a large quantity of a dense yellow residue remained after long boiling with HCl (1.20) and strong aqua regia. The HCl solution, however, contained a large quantity of platinum, as was shown by precipitating it in a pressure bottle with H_2S.

500 mgm. crude Ru were fused with 5 gm. Na_2O_2 and treated with water in the usual manner. The aqueous solution was dark orange-red, and upon adding HCl to the solution and residue, a clear, very dark red solution resulted.

100 mgm. commercial Rh were fused with Na_2O_2 and treated with water. The supernatant liquid after the precipitate settled was dark orange-yellow, and it remained so after decanting and acidifying with HCl, but it became colorless on boiling; these results being perhaps attributable to the presence of osmium. The black residue and adhering solution were treated with HCl: in the cold there was a large, finely divided cream-colored residue, but upon heating this almost entirely dissolved, yielding a dark yellow-orange solution.

P. 13, N. 7. — 200 mgm. Os were fused with Na_2O_2, the fused mass treated with water and HCl, and the liquid distilled (as in P. 13): after distilling 5 minutes, the dark orange distillate was replaced by fresh NaOH; after distilling 3 minutes longer, a yellow distillate corresponding in color to that given by 4–5 mgm. was obtained; on again replacing the distillate and boiling for 2 or 3 minutes longer, a colorless distillate giving no precipitate with $Na_2S_2O_8$ and HCl resulted. 25 ccm. HNO_3 (1.42) were then added to the residual solution, and the distillation continued for 10 minutes; the light yellow distillate was then treated with HCl and 2 ccm. saturated $Na_2S_2O_8$ solution: the precipitate obtained was pure white, showing that the osmium distilled over completely in less than 10 minutes and that the addition of HNO_3 is unnecessary.

P. 13, N. 8. — 500 mgm. crude Ru were fused with Na_2O_2, the fused mass treated with water and HCl, and the liquid distilled (as in P. 13): a weakly colored distillate, giving with HCl and $Na_2S_2O_8$ a small precipitate corresponding to 1–2 mgm., was obtained; this was probably due to a little osmium present in the material used. On further distillation into a new portion of NaOH, the latter remained colorless, showing that the ruthenium does not distil over.

P. 13, N. 10. — In one experiment 200 mgm. very finely powdered osmium, and in another 500 mgm. powdered osmium-iridium, were boiled in a distilling flask with strong aqua regia, and the distillate caught in NaOH solution: in neither case did the distillate give a dark-colored precipitate when tested with $Na_2S_2O_8$ and HCl.

P. 14, N. 1. — That the distillation and test with $Na_2S_2O_8$ will show 0.5 mgm. Os was proved by experiment.

The distillate obtained by distilling 1 mgm. Ru with dilute H_2SO_4 and $KMnO_4$ was tested with $Na_2S_2O_8$ by P. 14. A black precipitate was produced.

P. 16, N. 2. — The dense yellow residue of Pt_2O_3 insoluble in HCl and aqua regia, referred to in C. E. on P. 13, N. 5, was allowed to stand in the cold over night under water saturated with H_2S: it was completely converted to a black sulphide, which dissolved readily in aqua regia.

P. 18, N. 1. — As to the solubility of AgCl in NH_4OH, see Bodländer and Fittig, *Ztschr. phys. Chem.*, 39, 602 (1901); Whitney and Melcher, *J. Am. Chem. Soc.*, 25, 78 (1903).

500 mgm. Pb, as $PbSO_4$, were boiled with 20 ccm. NH_4OH (0.90), the mixture filtered hot, the filtrate nearly neutralized with HNO_3, and then acidified slightly with $HC_2H_3O_2$, and a few drops of K_2CrO_4 added: a considerable yellow precipitate of $PbCrO_4$ formed. The experiment was repeated with the modification that the NH_4OH solution was cooled before filtering: in this case a precipitate equivalent to only about 0.2 mgm. Pb resulted.

P. 19, N. 1. — The statement as to the quantity of $PbSO_4$ dissolved by 15 ccm. $NH_4C_2H_3O_2$ solution is based on a direct experiment.

A mixture of 500 mgm. Ba and 500 mgm. Sr, freshly precipitated as $BaSO_4$ and $SrSO_4$, was collected on a filter, a portion of 10 ccm. hot $NH_4C_2H_3O_2$ reagent was poured several times through the filter, the filtrate was acidified with $HC_2H_3O_2$, and a few drops of K_2CrO_4 were added: no precipitate resulted.

500 mgm. Sr, as $SrSO_4$, were boiled with 20 ccm. of the $NH_4C_2H_3O_2$ reagent, filtered while hot, and 30 ccm. of $(NH_4)_2CO_3$ added: after standing for 10 minutes, a precipitate estimated at 3–5 mgm. had separated.

For the solubility of $SrSO_4$ in HCl (1.04) and HNO_3 (1.032) see Fresenius, *Quantitative Analysis*, Am. Ed. of 1881, p. 815.

P. 20, N. 1. — 500 mgm. Sr, as freshly precipitated $SrSO_4$, were boiled for 10 minutes with 10 ccm. saturated Na_2CO_3 solution, the precipitate washed, and then treated with 10 ccm. cold HCl (1.12): it entirely dissolved.

500 mgm. Ba, as freshly precipitated $BaSO_4$, were boiled for 5 minutes with 25 ccm. saturated Na_2CO_3 solution; the solution was then decanted and the residue boiled for 5 minutes with 10 ccm. Na_2CO_3 solution; the solution was again decanted, the residue washed and treated with 10 ccm. HCl (1.02): it dissolved completely.

P. 20, N. 2. — For the theory of the equilibrium between two difficultly soluble salts in the presence of soluble ones with common ions and the results in the case of $BaSO_4$ and $BaCO_3$, see Nernst, *Theoretische Chemie*, 3d Ed., p. 498.

As to the solubility of $BaSO_4$, $BaCO_3$, $SrSO_4$ and $SrCO_3$ in water, see Kohlrausch and Rose, *Ztschr. phys. Chem.*, **12**, 241 (1893). It should not be forgotten, however, that the values given in the cases of the carbonates are much higher than correspond to the true solubility-products, owing to the effect of hydrolysis.

THE COMPOSITION OF SEWAGE IN RELATION TO PROBLEMS OF DISPOSAL.

By GEORGE W. FULLER.

Read March 26, 1903.

It is about fifty years ago that the first systematic analyses of sewage were undertaken in order to throw light upon problems of sewage disposal. From time to time it is well to review the progress made in fields of applied science in order to appreciate the relative advances in different branches of a subject, and especially to note wherein efforts towards improved conditions may be most fruitfully made.

In the middle of the last century the subject of sewerage and sewage disposal was practically in its infancy, and surrounded with many dissensions and uncertainties. The removal of municipal wastes by water carriage underground had been undertaken at London and a few other places, but very little progress in the development of this branch of public works had been made. In fact, London had just passed through the transitional stages whereby connections from the houses to the underground water channels were first prohibited, then permitted, and finally made compulsory by law.

The sewers themselves in those days were very crude affairs, and poorly designed as to alignment, size, slope, and velocities.

The disposal of sewage other than by discharging it into the nearest water course was very exceptional, although at the Craigentinny Meadows near Edinburgh and at Bunzlau, Prussia, sewage had been used for irrigation purposes since the middle of the eighteenth century. Numerous discussions were taking place as to the commercial value of sewage for fertilizing purposes, and of the means of taking advantage of the money value of sewage for this use. Hundreds of patented processes for the treatment of sewage were announced, most of which involved the use of some one or more of nearly all the chemicals which could then be made upon a commercial scale.

Largely through the efforts of several commissions and sanitary authorities in Great Britain, the next twenty-five years, or the third quarter of the last century, saw great progress made abroad regarding improved sewerage. At the end of that period, fundamental principles controlling the design of sewers were well understood by a considerable number of persons who had specially studied the matter; and efficient sewerage systems existed in various European cities, and in a few instances in this country. The last quarter of the century was characterized by wide dissemination of the knowledge and practice of sewer construction, until at present there are comparatively few cities and large towns which are not fairly well equipped in this respect.

Regarding sewage disposal, the situation in some respects has been and is different. In some instances this feature is so simple that it takes care of itself; in others there is no difficulty in applying sewage to land readily and economically; but in some cases, where cities are situated on relatively small streams, efficient sewage disposal has been and still is a difficult and expensive undertaking.

The disposal of sewage in relatively large volumes of water by dilution is still the prevailing method of disposal. Where purification processes are required, the practicability of irrigation and of intermittent filtration through areas of porous sand is well known. As to chemical precipitation, which has been so generally practiced abroad during the past generation, and where more than two hundred plants are now in operation, the time has come when the limitations to its merits are much more clearly recognized than formerly. To remove practically all of the suspended matters and one-half of the organic matter from sewage and to discharge the effluent into relatively small water courses is no longer permissible in numerous places abroad, and in this country instances are becoming more and more frequent where inland towns and cities must seek means for a substantially complete removal of decomposing matters before the sewage is discharged into small streams.

In Massachusetts, where relatively large areas of porous land are near at hand at moderate cost, and where sanitary matters are supervised with such eminent skill as is shown by the Massachusetts State Board of Health, these matters are not ordinarily of perplexing moment. In the South and West, however, where the glacial drift formation with its porous sand is absent, the interest is much keener in the

progress which is being made in a practical way in methods for the treatment of sewage by plants of artificial construction, occupying areas only a small fraction of that necessary for intermittent filtration. In the last ten to fifteen years, through the careful studies of the Massachusetts State Board of Health, and later by various authorities in England, progress in this direction has been made rapidly, at least so far as relates to the evidence which may be accumulated on a small, experimental scale.

As to the influence of various factors which affect the efficiency and cost of the so-called "rapid" methods of sewage treatment, the information as to results which may be expected from operations on a large scale is not so well crystallized as might be desired; and in fact is far less precise in its nature than that which relates to the purely constructive features of the collecting sewers to gather the sewage and convey it to the point of treatment.

In some ways the absence of crystallized evidence regarding these processes of sewage treatment depends upon matters of an analytical nature, dealing with the composition of sewage. This field is a very broad one, and it is not the purpose here to attempt to discuss it, but rather to point out a few ways in which more accurate information concerning the composition of sewage may perhaps facilitate progress in disposing of sewage so as to prevent nuisances from the bad odors resulting from putrefaction, which takes place when bodies of water are overcharged with polluting matters. No attempt is made here to consider that aspect of sewage disposal which deals with the infection of bodies of water by sewage, although it may be mentioned in passing that the literature upon this aspect of the subject needs thorough overhauling, in order that the matter shall be placed upon a more sound and practical basis than prevailing views indicate. In this latter task, laboratory men have important work to perform.

Strictly speaking, sewage disposal as referred to in this paper relates particularly to the dilution method, to modes of treatment preparatory to filtration, and to those so-called biological methods in which rapid rates of filtration are employed. No reference of a descriptive nature is made to these processes, which are doubtless well known to most of you, and which have been well outlined in recent articles by Professor Kinnicutt.

Among the fundamental principles associated with these sewage disposal problems may be noted the following:

1. The limitation in the amount of sewage which may be discharged into a water course without putrefaction setting in depends upon the oxygen-consuming properties of the sewage measured against the oxygen in the water of the stream, after making due allowance for the consumption of oxygen by the constituents of the water and by the matters contained on the bottom and sides of the stream.

2. Where it is necessary to filter sewage through beds of artificial construction it is highly advantageous to give the sewage a preparatory treatment by which there is removed a large portion of the matters suspended in the raw sewage. In order to make feasible high rates of filtration this is just as important as it is to afford a preliminary treatment to the muddy waters of the South and West prior to their filtration in a system of water purification works.

3. The rate of filtration which is permissible for sewage filters bears an inverse relation to the amount of organic matter contained in the applied liquid, other things being equal.

Each of these propositions is, of course, a large theme in itself. The purpose of this paper, as already indicated, is solely to refer to them in an illustrative sort of way in order to make plain, if possible, the significance which the composition of sewage, accurately known, bears to these important matters.

To the engineer who has to design artificially constructed purification works, and estimate the cost of their operation, it will be seen at a glance that it is highly desirable to know approximately the amount of suspended matter which on an average may be expected to be contained in the sewage before and after it has passed through various preparatory treatments. It is also important to know the amount of organic matter in the sewage to be applied to the filters in order to estimate a proper rate of treatment. This information as to organic matter is also essential in estimating approximately the amount of sewage that may be applied under given conditions to a stream with a certain flow without the putrefactive processes becoming a nuisance.

Here in Massachusetts, through the admirable equipment of the State Board of Health, these problems can be readily and safely solved as they present themselves. To one who has to deal with disposal problems in some other sections, the conditions are likely to be radically different, and the amount of detailed local data which may be obtained to serve as a guide is frequently very meagre indeed.

Not only are the data meagre, but frequently they are misleading. Thus, the results of analysis of a few scattering samples of sewage may do more harm than good, because they are not representative.

That sewage possesses a wide variation, both in quality and in quantity, at different hours of the day is, of course, very well known. In order to illustrate fully the significance of this to one who has to deal with the results of analyses of a few scattering samples, Table I is given. It shows the percentages which the volume of flow and the amount of the principal constituents of sewage at different hours of the day are of the average quantities. This table is computed from data given for the sewage purification works at Gardner in the Massachusetts State Board of Health Report for 1898, p. 624.

TABLE I.

COMPARISON OF THE PERCENTAGES WHICH THE FLOW OF SEWAGE AND THE AMOUNT OF ITS DIFFERENT CONSTITUENTS AT DIFFERENT HOURS ARE OF THE AVERAGES FOR THE DAY.

Hour.	Rate of Flow.	Residue on Evaporation.			Nitrogen as		Oxygen Consumed.	Chlorine.
		Total.	Dissolved.	Suspended.	Free Ammonia.	Albuminoid Ammonia.		
9-10 A.M.	124	143	126	180	150	180	158	99
11-12 "	116	160	159	162	157	155	167	114
1- 2 P.M.	123	129	131	125	107	107	110	127
3- 4 "	116	142	114	204	113	141	141	120
5- 6 "	107	123	137	93	116	99	92	217
7- 8 "	103	97	105	79	141	117	110	116
9-10 "	92	67	76	49	84	66	85	75
11-12 "	85	84	76	101	98	87	99	77
1- 2 A.M.	74	35	43	16	35	31	22	53
3- 4 "	70	28	39	6	8	15	16	38
5- 6 "	77	32	44	8	16	14	19	38
7- 8 "	114	69	74	59	101	87	82	61

The dangers of attaching too much significance to the results of limited data as to volume and strength of sewage have long been appreciated, and years ago resulted in the custom of rating the capacity of irrigation farms and intermittent sand filters according to the

population connected with the sewers per unit area of filtering surface. This was no doubt a wise custom, and it has served a useful purpose. But it has its limitations, owing to the fact that the amounts of some of the constituents of sewage are somewhat independent of the numbers of the contributing population, due especially to variations in quantity and quality of manufacturing wastes and of street washings which may be discharged into the sewers. Such limitations, of course, do not apply directly to residential and commercial communities which have separate sewers for the removal of storm water.

An endeavor has been made by the writer to gather together the available information as to the composition of sewage, partly with the view to securing data which would be of general assistance in connection with various problems in sewage disposal, and partly with the view to seeing wherein further studies are necessary in order to supplement data which are inadequate for allowing general deductions to be safely made.

The data herein compiled are somewhat fragmentary, and represent studies which have been made at odd times for several years of the available published records from sources with which the writer is more or less personally familiar. Acknowledgment is due here to the assistance of Mr. George A. Johnson, who has carefully reviewed the leading literature on the subject and compiled the various analyses in convenient form for use.

The composition of sewage representing different conditions can best be recorded by reducing the results of analyses and the gaugings of sewage flow to the common basis of the amount of the various constituents per capita per day. The data herein presented comprise, first, the published records of the amount of these constituents per capita, so far as they are known to the writer; and, second, the results which have been computed from the numerous analyses which in the last few years have been made and published in Massachusetts and in England.

The first records of which we have knowledge, showing the amount of the chief constituents of sewage per capita per day, are found in the notes and lectures by the late Dr. Letheby, which are reprinted in a book (p. 137) called "The Sewage Question," published in London in 1872 by Balliere, Tyndall & Cox. These results are the averages obtained from a great number of analyses by Dr. Letheby of the sewage discharged at all hours and at all seasons from the out-

falls of ten of the large London City sewers, whose ordinary rate of flow at midday was about five million gallons per day. These results are in close accord with those obtained in 1857 by Dr. Hoffman and Mr. Witt in their inquiries into the average composition of London sewage, and whose samples were taken hourly during the full twenty-four hours from the Savoy Street sewer, and mixed to produce fair average samples. Almost identical results were also obtained by Mr. Way in analyses of the Rugby sewage as the result of ninety-three analyses made from 1861 to 1863. Dr. Voelcker's estimate of the average composition is a little lower in some respects than that given by Dr. Letheby.

TABLE II.

DR. LETHEBY'S ESTIMATE OF THE AVERAGE AMOUNT OF THE PRINCIPAL CONSTITUENTS OF CITY SEWAGE EXPRESSED IN GRAMS PER CAPITA DAILY.

		TOTAL.	FROM EXCRETA.	FROM OTHER REFUSE.
Organic nitrogen	total,	15.1	10.1	5.0
	dissolved,	13.2	0.1	4.1
	suspended,	1.9	1.0	0.9
Dissolved matters	total,	136.0	43.0	93.0
	mineral,	98.5	10.0	88.5
	organic and volatile,	37.5	33.0	4.5
Suspended matters	total,	93.0	19.0	74.0
	mineral,	53.5	3.0	50.5
	organic and volatile,	39.5	16.0	23.5
Total solids	total,	229.0	62.0	167.0
	mineral,	152.0	13.0	139.0
	organic and volatile,	77.0	49.0	28.0
Phosphoric acid	total,	43.0	24.0	1.9
	dissolved,	2.1	1.4	0.7
	suspended,	2.2	1.0	1.2
Potash	total,	3.2	1.9	1.3
	dissolved,	3.0	1.5	1.5
	suspended,	0.2	0.4	—

One of the most interesting features of this table is the estimate of the relative amounts of the several constituents coming from excreta and from other sources.

In the above table it is to be noted that the organic matter is not recorded in the form of nitrogen as ammonias or of oxygen consumed, but that it is indicated only as a total quantity, doubtless obtained by the loss on ignition of the residue on evaporation, presumably including some volatile matter. However, it is of interest and important to note that the total nitrogen is given, presumably obtained by

a combustion process, and indicating that about one-fifth of the organic matter as recorded represents nitrogen.

In the special report on the examination of water supplies by the Massachusetts State Board of Health of 1890, p. 788, Mr. F. P. Stearns, then chief engineer of the board, estimated the leading constituents of sewage per capita daily, based upon analyses of the London sewage during the years 1883 and 1884, the Lawrence analyses as then available and a few analyses from Worcester, Mass., to be as follows:

TABLE III.

MR. STEARNS' ESTIMATE OF THE AVERAGE AMOUNT OF THE PRINCIPAL CONSTITUENTS OF SEWAGE EXPRESSED IN GRAMS PER CAPITA DAILY.

Nitrogen	as free ammonia,	5.6
	as albuminoid ammonia,	1.1
	total,[1]	8.9
Dissolved solids,		99.0
Chlorine,		19.0

[1] This is added by the writer, and is taken as the sum of the nitrogen as free ammonia and three times the nitrogen as albuminoid ammonia.

The next published record of which we have knowledge concerning the amount of constituents of sewage per capita is found in Mr. Goodell's translation of Professor Baumeister's work on "The Cleaning and Sewerage of Cities," the German edition of which appeared in 1890 and the English edition in the spring of 1891. Professor Baumeister apparently made very careful inquiries into the volume of water used by the sixteen English cities from which samples of sewage were analyzed by the Royal Commission on River Pollution during the early 70's, and paid especial attention to the question of whether the population connected with the sewers corresponded to the number of persons used in figuring the results per capita. His results are given in Table IV for sixteen representative English cities and also for the city of London, although it is presumable that his data for London are less satisfactory in some respects than those recorded in Table II.

TABLE IV.

PROFESSOR BAUMEISTER'S ESTIMATE OF THE AVERAGE AMOUNTS OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, EXPRESSED IN GRAMS PER CAPITA DAILY.

	LONDON.	AVERAGE OF SIXTEEN ENGLISH CITIES.
Nitrogen,	16	15
Dissolved matter,	129	127
Suspended matter { total,	112	79
Suspended matter { mineral,	71	43
Suspended matter { organic and volatile,	41	36
Total solids,	251	206

The next published records of the constituents of sewage per capita daily are found in the report of the Massachusetts State Board of Health for 1894, p. 474, where there is given an estimate from analyses, made under the charge of the writer, of the *fresh* sewage of Lawrence, the Worcester State Lunatic Hospital, Marlboro, Gardner and Framingham. The results are based on one set of analyses from each place, in which the sewage was collected hourly (with few exceptions), and gaugings made of the sewage at the same interval, thus allowing a representative analysis of the entire day's flow to be computed. No determinations were made of the total solids or of the matters in suspension.

There is considerable variation in the results obtained from the several places, due in part to difficulty in estimating the population upon the sewerage system. Connections had only been partially made at several of these places, and this required an estimate of the equivalent for a period of twenty-four hours of a considerable portion of the contributing population which worked in factories in the town and resided outside the district connected to the sewers. Another complication related to the relatively large volume of ground water which entered the outfall sewers. The constituents of this ground water had some connection with the contributing population, but for the most part it was believed to be independent thereof. In the results of the amount of constituents per capita, the ground water was disregarded, thus giving results which for this reason are perhaps a little too low. The average results of the five places mentioned are given below.

The remaining published record of the constituents of sewage per capita is given in the report of Mr. X. H. Goodnough, sanitary engineer, in the forthcoming report relative to the proposed Charles River

dam at Boston. It is based upon frequent analyses of sewage at Andover, Brockton, Marlboro and Spencer, Mass., and the quantity of nitrogen as albuminoid ammonia is estimated to be 1.02 grams per capita daily. The remaining constituents of sewage from these places are not given, as the albuminoid ammonia was used for a special purpose in connection with the permissible amount of pollution which streams may receive without offensive odor.

TABLE V.

ESTIMATE IN THE 1894 REPORT OF THE MASSACHUSETTS STATE BOARD OF HEALTH OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, EXPRESSED IN GRAMS PER CAPITA DAILY.

Oxygen consumed	2 minutes' boiling,	13.50
	5 minutes' boiling,	19.80
Nitrogen as	free ammonia,	6.40
	albuminoid ammonia,	2.25
	organic,	7.20
	total,	13.60
Chlorine,		16.00
Fats,		18.50
Bacteria,[1]		322.00

[1] Expressed as billions per capita daily.

Summarizing the results of published records of estimates of the amount of the chief constituents of sewage per capita daily, giving due weight to those data which are based upon the most numerous analyses, the following average may be obtained:

TABLE VI.

ESTIMATED APPROXIMATE AVERAGE AMOUNTS OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, BASED ON FOREGOING DATA AND EXPRESSED IN GRAMS PER CAPITA DAILY.

Oxygen consumed	2 minutes' boiling,	15.0
	5 minutes' boiling,	22.0
Nitrogen as	free ammonia,	7.0
	albuminoid ammonia,	2.5
	organic,	8.0
	total,	15.0
Chlorine,		19.0
Fats,		19.0
Dissolved matters	total,	136.0
	mineral,	99.0
	organic and volatile,	37.0
Suspended matters	total,	93.0
	mineral,	53.0
	organic and volatile,	40.0
Total solids,	total,	229.0
	mineral,	152.0
	organic and volatile,	77.0

The significance of the above data is not discussed until further evidence is presented, but there are several features which it is well to mention here, as follows:

This average is a composite result, and its several items do not specifically refer to the same sewage. For this reason the relative values are not as reliable as might be desired. The data of the last table represent in general the sewage from combined systems, due to the predominancy of English evidence, although the sewers in each of the Massachusetts cities studied in connection with Table V were designed, with the exception of those at Lawrence, on the separate system. The solids and suspended matters are based on London evidence, where there is a considerable amount of street washings during storms. The amount of manufacturing refuse in the sewage represented by the above data is comparatively small. As to the different forms of nitrogen in the organic matter, the total amount found in London is subdivided as indicated by the Massachusetts data of 1894, which, as stated, represent fairly fresh sewage. In fact, the dissolved oxygen was not exhausted in the samples as collected and analyzed, as will be seen by consulting the detailed data in the report mentioned.

One of the unfortunate features at present regarding data on the composition of sewage is the inadequateness with which analytical methods measure the capacity of the organic matter for consuming oxygen in connection with both filtration and dilution processes.

The old method of regarding the loss on ignition as organic matter is, of course, very crude, as the results also include quite a portion of volatile mineral matters, and, further, give no clue to the character of the organic material with reference to its power for consuming oxygen.

The amount of nitrogen in the form of the ammonias is more helpful, and is of much assistance in allowing comparisons to be made of purified sewage and of natural waters in which the organic matter is in a fairly stable condition. In raw sewage, however, the percentage of nitrogenous organic matter which appears in the form of the ammonias is quite variable, and depends upon a number of factors. Especially is this true of the nitrogen in the form of albuminoid ammonia as compared with the total organic nitrogen in raw sewage. This has led, in a few instances, to direct determinations of the nitrogen in the organic matter by means of the Kjeldahl process, a method

which, in the opinion of the writer, is worthy of a far wider adoption than it has met up to this time.

In connection with the carbonaceous matter, the oxygen consumed, or the oxygen absorbed, is a result which is obtained by a process that in some form or another has been applied since 1850. The number of modifications of the process, however, is so great that there is considerable difficulty in applying the results obtained at one laboratory to the conditions elsewhere, and in all cases the results indicate only a small fraction of the oxygen consumed under conditions in nature.

Illustrative of the varying relation of nitrogen in the form of albuminoid ammonia to the total organic nitrogen present in raw sewage, there is given below in Table VII the results of an experiment made in the Lawrence laboratory and published in the 1894 report of the Massachusetts State Board of Health, p. 461. A bottle of fresh sewage was analyzed just after its collection and again at frequent intervals, allowing the natural decomposition processes to take place at room temperature. In this table it is seen that fresh sewage contains dissolved oxygen, coming, of course, from the water supply which forms the principal portion of the sewage. It also contains nitrogen in the form of nitrates, as well as other salts which are completely oxidized. Through the agency of the bacteria and the oxygen dissolved in the water and yielded by the oxidized salts, the carbon of the organic matter is oxidized, and the organic nitrogen uniting with the hydrogen forms free ammonia.

Thus it is seen from the results in the table that the dissolved oxygen and the nitrates gradually disappear; the bacteria, for a time, increase; the oxygen consumed (carbonaceous matter) decreases; the nitrogen as free ammonia increases and the organic nitrogen (Kjeldahl) decreases. The nitrogen as albuminoid ammonia, however, remains approximately constant, notwithstanding that more than twenty parts of organic nitrogen are changed to free ammonia, and some five or six parts of free nitrogen escape into the atmosphere.

It is of interest in this connection to note that it is the soluble organic matter which is decomposed, and that there is comparatively little change in the suspended matter. Each day after the oxygen was exhausted there was a little air added during the mixing of the contents of the bottle to obtain a fair sample. Septic action took place, but not in the degree which would have been the case had the

TABLE VII.

CHANGES IN COMPOSITION OCCURRING IN FRESH LAWRENCE SEWAGE UPON STANDING IN A BOTTLE IN THE LABORATORY.
PARTS PER MILLION.

Date of Examination.		Free Ammonia.	Nitrogen as							Total Nitrogen.	Oxygen Consumed.		Per Cent. of Dissolved Oxygen.	Bacteria per Cubic Centimeter.
			Albuminoid Ammonia.			Organic. (By Kjeldahl.)			Nitrites and Nitrates.					
Day.	Hour.		Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Total.			Two Minutes.	Five Minutes.		
March 11	10.30 A.M.	18.5	5.8	2.1	7.9	31.4	9.1	40.3	3.5	62.2	85.0	132.0	57	1,190,000
" 11	12.30 P.M.	20.6	5.8	2.4	8.2	28.9	11.4	40.3	3.1	63.9	81.0	142.0	60	1,085,000
" 11	3.00 "	21.0	5.8	2.5	8.3	28.9	10.7	39.6	2.9	63.4	85.0	136.0	60	1,505,000
" 11	6.00 "	23.4	5.6	2.7	8.3	27.8	9.9	37.7	2.5	63.6	85.0	133.0	30	1,530,000
" 12	8.00 A.M.	40.7	4.9	3.9	8.8	11.6	12.2	23.8	0.3	64.6	74.0	107.0	0	20,475,000
" 12	12.00 M.	41.2	4.9	4.4	9.3	11.6	8.2	19.8	0.2	61.0	69.0	98.0	0	23,100,000
" 12	5.00 P.M.	41.2	4.2	4.2	8.4	11.6	10.1	21.7	0.6	62.7	69.0	98.0	0	20,000,000
" 13	10.30 A.M.	42.0	4.7	3.5	8.2	11.6	8.2	19.8	0.0	61.6	60.0	89.0	0	12,810,000
" 14	10.30 "	41.2	3.3	4.5	7.8	9.4	8.4	17.8	0.0	58.8	55.0	72.0	0	11,235,000
" 15	10.30 "	41.2	3.4	4.3	7.7	9.3	8.3	17.6	0.0	57.6	49.0	68.0	0	6,825,000
" 16	10.30 "	41.2	3.5	4.1	7.6	7.5	8.9	16.4	0.0	57 4	48.0	72.0	0	4,485,000
" 18	10.30 "	42.0	3.0	3.8	6.8	7.4	6.9	14.3	0.0	56.1	51.0	70.0	0	3,420,000
" 19	10.30 "	42.8	3.0	3.9	6.9	5.9	7.8	13.7	0.0	56.3	50.0	71.0	0	2,341,000

sewage first been seeded with a septic growth. This experiment suggests, however, that in large septic tanks the processes of decomposition and putrefaction may not be so rapid that a difference of a few hours in the period occupied by the flow of the sewage through the tank affects materially the soluble parts of the sewage passing through it. The physical aspect of the process should be considered, namely, that the velocity of flow should be reduced so that suspended matters may subside, and the tank should be large enough to retain suspended matters sufficiently long to allow solution of suspended organic matter to take place, and thus avoid cleaning the tank at too frequent intervals.

Table VIII shows some comparisons by percentage of the several amounts of the different forms of nitrogen as found at various intervals in the experiment last described.

TABLE VIII.

COMPARISON OF THE RELATIVE AMOUNTS OF NITROGEN IN DIFFERENT FORMS IN THE SEWAGE EXPERIMENTED WITH AS SHOWN IN TABLE VII.

Day.	Hour.	Percentage of Total Nitrogen Found as				Percentage which Nitrogen as Albuminoid Ammonia is of Organic Nitrogen (Kjeldahl).
		Organic Nitrogen. (Kjeldahl.)	Albuminoid Ammonia.	Free Ammonia.	Nitrites and Nitrates.	
March 11	10.30 A.M.	64	13	30	6.0	20
" 11	12.30 P.M.	63	13	32	5.0	20
" 11	3.00 "	62	13	33	5.0	21
" 11	6.00 "	59	13	37	4.0	22
" 12	8.00 A.M.	37	14	63	0.4	37
" 12	12.00 M.	32	15	67	0.3	47
" 12	5.00 P.M.	35	13	66	0.0	39
" 12	10.30 A.M.	32	13	68	0.0	41
" 14	10.30 "	30	14	74	0.0	44
" 15	10.30 "	31	13	72	0.0	44
" 16	10.30 "	29	13	72	0.0	46
" 18	10.30 "	25	12	75	0.0	48
" 19	10.30 "	24	12	76	0.0	50

The amount of organic nitrogen present in sewage was determined in early days by the combustion method. Later it was estimated

as twice the nitrogen in the form of albuminoid ammonia, and more recently it has been taken as three times. In preparing balance sheets recording the changes through which sewage passes when treated by various processes, particularly those preparatory to filtration, and including the septic process, it seems to the writer to be highly desirable to know more accurately about the relative changes in nitrogenous matter. Such data can hardly fail to add to our knowledge of these subjects, and it is quite possible that the amount of nitrogen in the form of free ammonia as compared with the total nitrogen present in partially purified sewage may serve a useful purpose in the control of some preparatory treatments.

An effort has been made to find a formula for converting nitrogen in the form of albuminoid ammonia into organic nitrogen, giving due recognition to the range of free ammonia present in the sewage. It has been found that fair results, as a rule, are obtained in a majority of cases of Massachusetts sewages by using the following formula:

$$\text{Organic nitrogen} = \frac{12 \text{ times the square of the nitrogen as albuminoid ammonia}}{\text{nitrogen as free ammonia}}$$

In the case of sewages which are very dilute, or of partially treated sewages, this formula does not work well, as will be seen in the next table, where comparisons are shown of the amount of organic nitrogen as actually determined by the Kjeldahl process and as estimated by this formula. The data from the several Massachusetts cities are averages of several analyses as described in the reports of the State Board of Health for the respective years. The experiment recorded in Table VII is also included, as well as data from Manchester given by Sir Henry Roscoe in his testimony before the Royal Commission on Sewage Disposal, 1902, Vol. II, p. 214.

TABLE IX.

COMPARISON OF THE AMOUNTS OF NITROGEN IN SEVERAL FORMS FOUND IN VARIOUS SEWAGES, WITH REFERENCE TO THE RELATION BETWEEN ALBUMINOID AMMONIA AND ORGANIC NITROGEN BY THE KJELDAHL METHOD.

PARTS PER MILLION.

SOURCE OF SEWAGE.	DATE.	NITROGEN AS				PER CENT. WHICH NITROGEN AS ALBUMINOID AMMONIA IS OF	
		ORGANIC (KJELDAHL).		ALBUMINOID AMMONIA.	FREE AMMONIA.	ORGANIC NITROGEN.	FREE AMMONIA.
		Determined.	Estimated.				
Worcester, Hospital,	1894	32.5	68.00	5.9	6.1	18	97
Worcester, Hospital,	1895	32.5	47.00	5.5	7.7	17	72
Marlboro,	1894	24.8	46.00	10.7	30.1	43	36
Marlboro,	1894	12.6	15.50	5.0	19.4	39	26
Framingham,	1894	16.7	16.50	5.9	25.3	35	23
Framingham,	1895	14.5	14.10	4.3	15.7	30	27
Gardner,	1894	11.2	11.70	3.1	9.5	28	33
Lawrence (fresh sewage),	1894	18.5	15.60	4.4	14.9	24	30
Lawrence (fresh sewage),	1895	21.6	25.00	5.3	13.5	25	39
Lawrence (Station sewage),	1894	13.0	11.50	5.2	28.1	40	19
Lawrence (Station sewage),	1895	15.8	15.80	6.1	28.1	38	22
Lawrence sewage upon standing in bottle in laboratory. — 1st day,		39.5	38.80	8.2	20.9	21	39
2d and 3d days,		21.3	22.00	8.7	41.3	41	21
4th to 8th days,		16.0	15.80	7.4	41.7	46	18
Effluent of Ppt. tanks at Manchester, Eng., average of 6 analyses covering 2 weeks each. — 1st set,		6.1	2.30	2.0	21.2	33	9
2d set,		5.3	1.35	1.4	17.5	26	8
3d set,		5.1	1.04	1.3	19.5	25	7

It does not seem likely that a formula or a series of formulas can be developed which can equal in reliability the results obtained by actual determinations of the organic nitrogen by the Kjeldahl process. More information concerning organic nitrogen is certainly necessary, and it will be a simple matter later on to judge of the practicability of formulas for conversion.

Regarding the determination of oxygen consumed, it is the general custom in this country to make the determination by adding acid and

permanganate solution to the liquid, and heating the same for a period of five minutes before making a titration to obtain the result. In some places, as at Lawrence, it is customary to limit this period of boiling to two minutes. In Germany, however, the period of boiling is generally extended to ten minutes. In England, the temperature at which the liquid, after being treated with chemical solutions, is allowed to stand is 80° F., and the results are observed as to the oxygen consumed after periods of three minutes, fifteen minutes and four hours, respectively. It is readily seen that the results obtained and published from such a different number of methods are bound to be very variable, and to give rise to much confusion in making deductions from the evidence accumulated at various places.

It would be very desirable indeed if there could be determined the absolute amount of oxygen consumed, such as would indicate the total amount of oxygen necessary in order to oxidize crude organic matter completely. This is a point which apparently could be studied advantageously along lines which are indicated farther on.

Any of the methods for determining oxygen consumed, if carefully carried out, of course give data of assistance in connection with various problems, especially in estimating the degree of purification effected by a process. It is highly important, however, that the method by which oxygen consumed is obtained should be recorded in connection with all important reports and analyses. If this is done, it is possible within certain limits to convert the results obtained by any method into those which would be obtained by others.

Careful inquiry has been made in the endeavor to ascertain factors which might be used with moderate confidence for converting to an equivalent basis the results obtained from the various methods of estimating oxygen consumed. These factors, made up of many average comparisons, are given in the next table:

TABLE X.

APPROXIMATE COMPARISON OF AVERAGE AMOUNTS OF OXYGEN CONSUMED BY SEWAGE AND SEWAGE EFFLUENTS AS SHOWN BY DIFFERENT METHODS.

METHOD.	TEMPERATURE OF SOLUTION.	PERIOD OF CONTACT.	RELATIVE RESULTS.
Kübel, as practiced at Boston and generally in America,	Boiling.	5 minutes.	1.00
Kübel, as practiced at Lawrence, Mass.,	Boiling.	2 minutes.	0.65
Kübel, as practiced in Germany,[1]	Boiling.	10 minutes.	1.25
English official tests,	80° F. 80° F. 80° F.	3 minutes. 15 minutes. 4 hours.	0.20 0.35 0.60
"Absolute" oxygen consumed,	Boiling.	4 hours.	4.00

[1] German results generally refer to "permanganate consumed" (*oxidirbarkeit*) and should be divided by four to give oxygen consumed.

With regard to the data used in arriving at these factors, it may be said that these comparisons between the Boston and Lawrence methods are obtained from numerous published records of the Massachusetts State Board of Health. The comparisons of the Kübel method, after heating five minutes and ten minutes, respectively, are based upon very limited information which was obtained by the writer a number of years ago. Comparisons of the Kübel boiling method and the official English method at 80° F. are obtained from Blair's book on "Organic Analyses of Waters," and from comparisons made in the laboratory of Professor Kinnicutt, of Worcester, and communicated privately to the writer.

As to the absolute oxygen consumed, the evidence is very limited indeed, being confined to about half a dozen observations given by Blair, p. 49, and by Sir Henry Roscoe in his testimony before the Royal Commission on Sewage Disposal, Vol. II, p. 212.

Regarding the factors given in Table X, of course it must be clearly borne in mind that in most instances they are only rough approximations for the purposes of the immediate present. It is believed, however, that they may be of some assistance in making comparisons until more adequate and reliable data are available. The discrepancies in the data obtained at different places indicate that these factors should be carefully worked out for different kinds of sewage.

Concerning the available evidence on the composition of sewage with reference to ascertaining the amounts of leading constituents per capita daily, as shown by analyses published within the last few

years in Massachusetts and England, it is unfortunate that so many records have to be ignored. This is on account of the data not being representative for the full twenty-four hours daily, and also lacking in the determination of so many constituents; and on account of inability to establish, even roughly, the relation between samples of sewage analyzed and the corresponding population and the volume of sewage flow.

The towns and cities in Massachusetts from which samples of sewage have been collected and analyzed in a manner to serve present purposes include Framingham, Gardner, Marlboro, and Worcester.

Table XI shows the estimated average composition of the sewage of each of these places, based on several series of hourly or bi-hourly samples for the full twenty-four hours per day, with corresponding gaugings of the sewage flow. The details will be found in the reports of the Massachusetts State Board of Health for the year in which the respective series of samples were collected, the dates of collection of the several series of samples being as follows:

Framingham, Sept. 11, 1894; Oct. 30, 1895; and April 17, 1899.
Gardner, July 19–26, inclusive, 1898; Jan. 31–Feb. 3, inclusive, 1899.
Marlboro, Aug. 23–30, inclusive, 1898.
Worcester, Sept. 4–10, inclusive, 1895.

The estimate of the average volume of sewage per capita daily is based on the following number of persons connected with the several sewerage systems: Framingham, 6,000; Gardner, 2,500; Marlboro, 1,200; and Worcester, 90,000. Worcester sewers in 1895 were on the combined plan, and the sewage contains iron and acid from steel works. At the other places the sewers are on the separate plan, and, generally speaking, receive only domestic sewage.

TABLE XI.

AVERAGE ANALYSES OF REPRESENTATIVE SEWAGE FROM MASSACHUSETTS CITIES, WITH ESTIMATED CORRESPONDING VOLUME PER CAPITA DAILY. PARTS PER MILLION.

		CITY (MASS.).			
		Framingham.	Gardner.	Marlboro.	Worcester.
Average daily flow of sewage per capita,	U. S. gallons,	73.0	100.0	113.0	150.0
	Imp. gallons	63.0	83.0	95.0	125.0
	liters,	275.0	375.0	430.0	562.0
Oxygen consumed,[1]		62.0	34.0	20.0	78.0
Nitrogen as	free ammonia,	21.5	15.8	7.7	11.2
	albuminoid ammonia,	5.7	3.8	2.7	5.2
	organic,[2]	18.1	10.7	11.3	29.0
	total,	39.6	26.5	19.0	40.2
Chlorine,		64.0	30.0	47.0	63.0
Dissolved matters	total,	312.0	185.0	232.0	548.0
	mineral,	200.0	110.0	181.0	357.0
	organic and volatile,	112.0	75.0	51.0	191.0
Suspended matters	total,	289.0	102.0	68.0	360.0
	mineral,	63.0	27.0	15.0	178.0
	organic and volatile,	226.0	75.0	53.0	182.0
Total solids	total,	601.0	287.0	300.0	908.0
	mineral,	263.0	137.0	196.0	535.0
	organic and volatile,	338.0	150.0	104.0	373.0

[1] These results are obtained by boiling for five minutes.

[2] This is estimated by the formula already given.

Table XII contains the estimated average composition of sewages in certain European cities where the data are sufficiently numerous to serve present purposes of comparison. The estimates are based upon recorded analyses of sewage, as follows:

Huddersfield. — The average analysis of sewage in this manufacturing city (population about 100,000) is based upon the mean result of hourly samples collected for twenty-four consecutive hours on five different occasions averaged with the mean analysis of the sewage from August, 1898, to February, 1900. The serial analyses are recorded on pp. 14–18 of the report of Mr. K. F. Campbell, borough engineer, on "The Sewage Problem," dated May, 1900. The latter analyses are stated by Mr. Campbell in the report of the Royal Commission on Sewage Disposal, 1902, Vol. III, p. 449. The sewers are on the combined plan, and 29 per cent. of the dry weather flow is made up of trade refuse.

Leeds. — This analysis represents sewage from a manufacturing city (population about 430,000) and covers the period from November, 1898, to June, 1900, as given by Colonel Harding in his testimony

to the Royal Commission, 1902, Vol. II, p. 382. The sewers are on the combined plan, and contain much trade waste, especially iron liquor.

Leicester. — The average analysis from this city (population about 220,000) represents the results from mixed half-hourly samples taken one day a week for a period of about one year, September, 1898, to September, 1899, inclusive, as recorded in the report of the borough engineer, Mr. E. G. Mawbey, upon the experiments made at Leicester and also as given by him in his testimony before the Royal Commission, 1902, Vol. II, p. 440. The sewers are on the combined plan, here, and receive wastes from dye works and wool-scouring establishments.

London, Northern Outfall. — This average analysis refers to a population of about 3,250,000, and is estimated from records obtained at different periods during the past twenty years. The more recent ones were obtained from bi-hourly samples collected day and night and averaged each day, regardless of the volume of flow. The data include an average analysis for 1883, as reported by Mr. Dibdin, report of the Royal Commission, 1884; an average for the year 1893, as recorded by the late Mr. Santo Crimp in his text-book, p. 158; an average for the year 1894, as recorded by Mr. Dibdin in his paper before the Institution of Civil Engineers, Vol. CXXIX, p. 55; and the results obtained during the past five years, as reported by Professor Clowes in his testimony before the Royal Commission on Sewage Disposal, 1902, Vol. III, as follows: for the period from September, 1898, to April, 1899, p. 458; for the year 1900, on p. 375; and for the period of November, 1900, to August, 1901, on p. 419. The first set of analyses is the most complete, and the estimated average as recorded in Table XII shows some features which are based upon the conditions which governed for the year 1883. Ground water and manufacturing refuse do not seem to have been a very important factor at this place. The sewers are on the combined plan.

London, Southern Outfall. — This average result is based upon the data for the years 1893 and 1894, as given by Mr. Dibdin in the same reference as for the northern outfall, also the analyses recorded by Professor Clowes for the period from November, 1889, to July, 1900, given in his testimony before the Royal Commission, Vol. III, p. 455. These analyses represent a somewhat different sewage than that of the northern outfall, due in part to manufacturing refuse, but more particularly to ground water entering the outfall sewer along the

salt marshes on the way to the outfall at Crossness. The sewers are on the combined plan, and receive the sewage of about 1,675,000 people.

Manchester. — The average analysis of the sewage from this manufacturing city (population about 562,000) is based on hourly samples, which were mixed in equal proportions, from Monday noon until Friday noon, to give four representative daily samples per week. The data cover the period from May 16, 1900, to January 24, 1901, as found in Tables VII and VIII and on p. 37 of the Report of the River Department for the year ending March 27, 1901. Much trade refuse is received by the sewers, which are on the combined plan.

TABLE XII.

AVERAGE ANALYSES OF SEWAGE FROM ENGLISH CITIES, WITH ESTIMATED CORRESPONDING VOLUME PER CAPITA DAILY. PARTS PER MILLION.

		City.					
		Huddersfield.	Leeds.	Leicester.	London (North).	London (South).	Manchester.
Average daily flow of sewage per capita	U. S. gallons,	108.00	60.0	60.0	48.0	60.0	72
	Imp. gallons,	90.00	50.0	50.0	40.0	50.0	61
	liters,	410.00	225.0	225.0	180.0	225.0	275
Oxygen consumed	4 hours at 80° F.,	99.00	126.0	107.0	80.0	67.0	118
	5 minutes at 212° F.,	165.00	210.0	180.0	133.0	112.0	197
Nitrogen as	free ammonia,	10.70	23.6	—.	39.0	34.5	24
	albuminoid ammonia,	6.05	11.3	14.2	4.3	4.3	6
Chlorine,		123.00	—	—	132.0	267.0	170
Dissolved matters	total,	715.00	1070.0	1045.0	870.0	1093.0	940
	mineral,	597.00	—	—	565.0	755.0	470
	organic and volatile,	118.00	—	—	305.0	338.0	470
Suspended matters	total,	346.00	610.0	635.0	483.0	408.0	370
	mineral,	164.00	240.0	—	228.0	183.0	200
	organic and volatile,	182.00	370.0	—	225.0	225.0	170
Total solids	total,	1061.00	1680.0	1680.0	1353.0	1501.0	1310
	mineral,	761.00	—	—	793.0	938.0	670
	organic and volatile,	300.00	—	—	560.0	563.0	640

In making estimates of the average composition of sewage from the foregoing data, it is necessary to divide them into classes according to the nature of the sewage, as follows: Domestic sewage (separate system) from the small Massachusetts cities; domestic sewage and street washings (combined system) from the metropolitan district of London; and the domestic sewage, street washings and trade wastes (combined system) from the several large manufacturing cities.

TABLE XIII.

QUANTITIES OF PRINCIPAL CONSTITUENTS IN GRAMS PER CAPITA DAILY OF SEWAGE OF VARIOUS CITIES CLASSED ACCORDING TO THE GENERAL NATURE OF THE SEWAGE.

		Domestic Sewage from Small Cities.				Domestic Sewage and Street Refuse from the Metropolitan District of London.			Domestic Sewage, Street Refuse and Trade Waste from Manufacturing Cities.					
		Framingham.	Gardner.	Marlboro.	Average.	North.	South.	Average.[1]	Huddersfield.	Leeds.	Leicester.	Manchester.	Worcester.	Average.
Oxygen consumed,		17.0	13.0	9.0	13.0	24.0	25.0	25	67.0	47.0	40.0	55.0	44.0	50.0
Nitrogen as	albuminoid ammonia,	1.6	1.4	1.2	1.4	0.8	1.0	1	2.5	2.5	3.2	1.7	2.9	2.5
	free ammonia,	5.9	5.9	3.3	5.0	7.0	7.8	8	4.4	5.3	—	6.7	6.3	5.5
	total,	—	—	—	9.7	—	—	13	—	—	—	—	—	—
Chlorine,		18.0	11.0	20.0	16.0	24.0	60.0	24	50.0	—	—	47.0	35.0	44.0
Dissolved matters	total,	86.0	69.0	100.0	85.0	157.0	248.0	157	294.0	240.0	236.0	260.0	308.0	268.0
	mineral,	55.0	41.0	78.0	58.0	102.0	172.0	102	245.0	—	—	130.0	201.0	178.0
	organic and volatile,	31.0	28.0	22.0	27.0	55.0	76.0	55	49.0	—	—	130.0	107.0	90.0
Suspended matters	total,	80.0	38.0	29.0	49.0	87.0	92.0	87	142.0	137.0	143.0	102.0	202.0	145.0
	mineral,	18.0	10.0	6.0	11.0	41.0	41.0	41	67.0	54.0	—	55.0	100.0	69.0
	organic and volatile,	62.0	28.0	23.0	38.0	46.0	51.0	46	75.0	83.0	—	47.0	102.0	76.0
Total solids	total,	166.0	107.0	129.0	134.0	244.0	340.0	244	436.0	377.0	379.0	362.0	510.0	413.0
	mineral,	73.0	51.0	84.0	69.0	143.0	213.0	143	312.0	—	—	185.0	301.0	247.0
	organic and volatile,	93.0	56.0	45.0	65.0	101.0	127.0	101	124.0	—	—	177.0	209.0	166.0

[1] The nitrogen is not an exact average, but is given in round numbers in partial conformity with the data of Dr. Letheby. See Table II.

Table XIII shows the individual data, with averages of the composition in grams per capita daily, of the sewage of the three classes above stated. These data are self-explanatory, except that it may be stated that the oxygen consumed in each case refers to the Kübel method and a five-minute period of boiling in accordance with the provisional conversion factor given in Table X. Regarding the London average, the chlorine and various amounts of solids are based on the records obtained at Barking (southern outfall) because they are more numerous than those available from Crossness (southern outfall), and also for the reason that the data from the latter are complicated as to chlorine and dissolved matters, due to the ground water entering the outfall sewer. The nitrogen results at London are rather lower than is expected from the data of Dr. Letheby, and for this reason the estimated average as stated is given in round figures. The total nitrogen in each average is an estimate, based somewhat, in the absence of actual data, upon general information.

It is true that the average data for the several classes of sewage as here presented are not based on as comprehensive knowledge of exact local conditions as is desirable, nor do they in every instance include the records from as many cities as is necessary to make them thoroughly representative. To persons of a precise turn of mind it is not difficult to point out inconsistencies and the lack of consideration of important features, and to inquire what specific influence is produced by different modes of living of the population considered; by different proportions of paved streets, by pavings of different kinds, and by the cleanliness with which the streets are kept; by the frequency and intensity of rainfall with especial reference to storm overflows in the trunk sewers; and by differences in the amount and character of waste products of various industries.

On the other hand, it is not to be forgotten that these estimated averages are ordinarily far safer guides than are results of many scattering analyses, as will be appreciated by comparing the range in quantities given in Table XIII for the several classes of sewage with that in Table I. Again, in considering sewage disposal problems it is the duty of the engineer and sanitarian to give due regard to the future, for which no specific individual data are available, and judgment must be based on well-digested generalizations from past experiences which are thoroughly understood.

Knowing approximately the number of persons connected to a

sewerage system and the average flow, which information within certain limits is essential for the proper design of the collecting sewers, it is feasible to estimate the average composition of the sewage from such data as given in Table XIII. For purposes of ready comparison it is convenient to prepare tables showing the composition of sewage, based on such averages and corresponding to different degrees of dilution. It is unnecessary to burden this paper with such voluminous tables, but it may be stated here that "grams per capita daily" give the same figures for the several constituents, corresponding to the different forms of expressing the analyses, when the volume of sewage in United States gallons per capita daily is as follows:

Parts per million . . .	264.0	gallons.
" " 100,000 . . .	26.4	"
Grains per U. S. gallon . .	15.4	"
" " Imperial gallon .	18.5	"

For some time the writer has used tables prepared from the data of Table XIII to show the estimated composition of sewage corresponding to a wide range in volume per capita, and has found them of much assistance.

Before dismissing the subject of the average composition of sewage it may not be amiss to mention that it is somewhat surprising to note how few data, which may be used for this purpose even with moderate safety, are available at this time, fifty years since systematic sewage analyses were begun. This is partly due to the fact that the majority of the many thousands of sewage analyses which have been made are not representative samples, nor are the individual conditions which they represent recorded in a manner to permit of their general use. It is also caused in part by the tendency of the past dozen years to make only partial analyses for the purpose of indicating quickly and frequently the degree of purification effected by purification processes under trial.

Regarding methods of sampling, it is gratifying to note that there has been much improvement during the past five years at various places. This is very important, as it is easy to obtain distorted data by poor sampling. Looking at Table I it is seen that a comparison of the strongest sewage with the weakest, even if no purification

process were employed, would show a high percentage of purification should such samples be collected to indicate the efficiency of a process, as is quite possible under some circumstances, especially if only partial analyses are made.

As to methods of analyses as regularly practiced, there have not been many important changes in thirty years. This has its advantages and disadvantages. The advantages relate to the comparableness of general data from the same laboratory, and have resulted in a large fund of information to assist in arriving at certain leading features in connection with purification processes. The disadvantages are that the analytical data are not sufficiently comprehensive to allow thorough study of many important details such as are necessary in considering this subject to its logical conclusions. In the opinion of the writer the time has come when it is much wiser to make fewer analyses and make them more complete, as well as having the samples more thoroughly representative, not only of sewage, but also of effluents. It is also important to see that the samples of sewage do not change materially in composition during the interval between collection and examination.

Returning to the three principles of sewage disposal stated in the first part of this paper, it may be said that in connection with the preparatory treatment of sewage preliminary to filtration, we need more data regarding both the quantity and quality of suspended matters in various classes of sewage. This refers especially to the organic matter and with especial reference to street refuse and mill wastes. The latter form a study by themselves, and in manufacturing cities should be studied separately from the domestic sewage so far as estimates of the composition of sewage are concerned, although the data in the last column of Table XIII are of general assistance. At present the relative amounts of organic matter in solution and in suspension in sewage, as they actually exist at purification works (not in the laboratory), are not well known, and no attempt in this paper has been made to estimate them, except so far as indicated by loss on ignition.

Regarding preparatory treatments for sewage, especially the septic process, and methods of filtration involving high rates with a degree of purification sufficient only to secure a stable effluent, it is believed that detailed studies of the changes in the organic matter similar to and extending beyond the special experiment outlined in Table VII

will advance our practical knowledge of these processes and lead to a more advantageous application of them. If the data in the table mentioned are representative, then it seems that albuminoid ammonia determinations are of far less value than the organic nitrogen by the Kjeldahl method, and possibly may be omitted with safety. Certainly they now do not seem to have sufficient value to be made to the exclusion of the Kjeldahl process. The future of the albuminoid ammonia determination, judged strictly on its merits, appears to depend on the practicability of conversion factors such as already noted on p. 146, when considered for sewage work. This remark does not apply to natural waters. It seems to the writer that the time is ripe for a thorough review and comparison of methods for determining organic matter in sewage on a scale as comprehensive as made in connection with natural waters under Professor Mallet for the National Board of Health over twenty years ago. To the thought of the writer, the future of sewage chemistry cannot depend upon the question of convenience of manipulation in the laboratory, or that of the degree of skill of laboratory assistants.

Concerning the disposal of sewage into streams and ponds, the statement was made by Dr. Letheby in 1867 that (English) sewage if diluted with at least twenty volumes of water will not only be made inoffensive, but will be thoroughly destroyed after flowing a dozen miles or so. In 1878 the River Pollution Commission of Great Britain concluded that no river in that country was long enough to allow a complete disappearance of sewage matter discharged into it. Mr. Rudolph Hering concluded in 1888 (see Proceedings for that year of American Public Health Association) that to render sewage inoffensive to communities situated on a stream below the point of discharge, so far as putrefaction is concerned, it is necessary to have a dilution of at least 2.5 to 3 cubic feet per second per thousand population connected to the sewerage system. In 1890, the Massachusetts State Board of Health published a report by Mr. Stearns upon this matter, in which he reviewed very carefully the Massachusetts evidence then available, and including an estimate of the average composition of sewage (see Table III). His conclusions were that a dilution of 2.5 cubic feet per second per thousand persons was the least permissible, and that under certain conditions it might be necessary to have 7 cubic feet in order to guard against offensiveness.

In England, several river boards have adopted the standard, independent of questions of infection, of 1 grain of oxygen absorbed (4 hours at 80° F.) per Imperial gallon for the purity of sewage effluents discharged into relatively very small water courses. The practicability of this standard has been exploited by means of the so-called incubator test, which throws much light upon the biological and chemical aspects of this matter of non-putrescible water.

From these and other studies of an engineering, chemical, and biological nature, fairly satisfactory general rules may be drawn regarding the amount of organic matter which may be safely discharged into streams. But for certain specific cases the data are not as definite as desired, and, as stated by Mr. Freeman in his report to the Charles River dam committee, it was necessary to make further studies in order to learn "just where to draw the line in avoiding unnecessary expense." The reports made to him by Mr. Goodnough, Mr. Clark, and Dr. Field were of much assistance, and it would be advantageous if they were continued and made to cover a wider range of conditions.

In studying exhaustively the chemical and biological changes which take place in polluted waters, and the conditions under which putrefaction may be avoided, it is believed that the relative significance should be studied of the "absolute oxygen-consuming powers" of the organic matter in sewage or effluent expressed in terms which can be readily appreciated; of the oxygen dissolved in the sewage or effluent, together with that which may be yielded by nitrates, sulphates, and other constituents of the liquid; of the oxygen similarly contained in the water into which the sewage or effluent is discharged; of the oxygen which may be received in the water by means of aëration and from higher forms of vegetable life; and of the absolute oxygen-consuming powers of the organic matter in the water of the stream and in the sediment on the bottom and sides of the stream itself. To these factors should be added the effect of the very important items of temperature and the period of time during which biological changes may take place.

The above paragraphs may give the impression that they are written without due appreciation of the difficulties involved in applying the suggestions made, and of the advance in knowledge resulting from chemical and biological studies as they have been made in the past ten years. Such an impression is not correct, as the difficulties

attending the study of such a complex subject are realized. While it is not feasible to develop laws of mathematical precision, it is believed that it is possible to obtain more definite knowledge of various factors under various known conditions. As to the part played by analytical data in the development of matters of sewage disposal, their value has unquestionably been great. In the opinion of the writer, however, methods employed for studying the composition of sewage in its various phases have fallen somewhat into a rut. It seems questionable whether the amount of added knowledge which may be obtained from a continuance of present methods year after year is going to be commensurate with the cost. In fact, it seems that the time is approaching when it is worth while to consider a recasting of the program for sewage analyses. This may be thought to be unwise because future data would not be comparable with the past. This objection is readily met by stating that there should be omitted in the future no determination of value. In fact, it is more complete data which are now needed. Samples for analysis should be more representative and should be freer of the influences of changes between collection and examination. Partial analyses should not refer to certain of the regular tests, but be supplementary to full analyses, and with new methods cover special points as they arise. By such a program, even if necessary to reduce the cost of work done, it is believed that practical knowledge of the composition of sewage can be placed on a more substantial basis.

BOOK REVIEWS.

Analytical Chemistry.[1]

American chemists and students of chemistry will welcome Mr. Hall's translation of Dr. Treadwell's work on qualitative analysis, for a most excellent book has been rendered into good English, and the clearness and precision of the original are fully preserved in the translation. The fact that the first German edition was exhausted within two years from its issue speaks well for the reception which it has met in that country, and it seems quite certain that its American critics will be obliged to confine themselves mainly to a simple review.

The first thirty-five pages of the book are devoted to "General Principles," and contain sections on oxidation, reduction, chemical mass action, ionization, hydrolysis, blowpipe and bead reactions, and reagents. The explanations of oxidation and reduction are beautifully simple, and the illustrative reactions are well chosen and comprehensive. The chemical method is used, while some chemists might perhaps prefer the more modern method of considering oxidation and reduction a simple addition or subtraction of electrical charges. The chapters on chemical mass action and the ion theory of Arrhenius, as well as the application of both to the question of hydrolysis and indicators, is so simply stated that only the dullest of students can fail of comprehension. The strength of reagents recommended is based upon the idea of equivalents; twice normal, normal, and half normal solutions are used, so far as possible, in the hope that the student will carry along the idea of quantity as well as kind throughout the analysis.

The following two sections, "Reactions of the Cathions," and "Anions," occupy 328 pages. Here will be found the chief value of the book as a work of reference, for the properties and reactions of the

[1] Treadwell, F. P. Analytical Chemistry. Translated from the second German edition by William T. Hall. Volume I. Qualitative Analysis. New York: John Wiley & Sons. $3.00.

metals and the metalloids are gathered together for the purpose of the analyst in a manner that is unsurpassed. Italics are frequently but not excessively used. Structural formulas are most clearly drawn, and must form an important element in the instruction. No attempt is made to make the method of instruction hinge entirely upon modern physical chemistry, but the important deductions from the theory of dissociation and the action of mass are frequently pointed out and their application explained. Reversible reactions are frequently exemplified and methods of overcoming the difficulties arising therefrom in analysis made clear. Altogether, these sections of the book cannot be praised too highly, and the reviewer knows of no book to which he would rather refer students for the properties and reactions of the ions.

The section on "Course of Analysis," containing forty pages, is undoubtedly the one upon which the greatest difference of opinion will arise among chemists. It is unusually full and complete, omitting little but the rare-earths. It seems, however, to be rather complicated and somewhat disconnected, and it is doubtful if the almost complete course of blowpipe analysis, which is required in the examination preliminary to the regular analysis, will meet with general approval. Bunsen's classifications for acids is used. The tables for the common metals present no unusual feature.

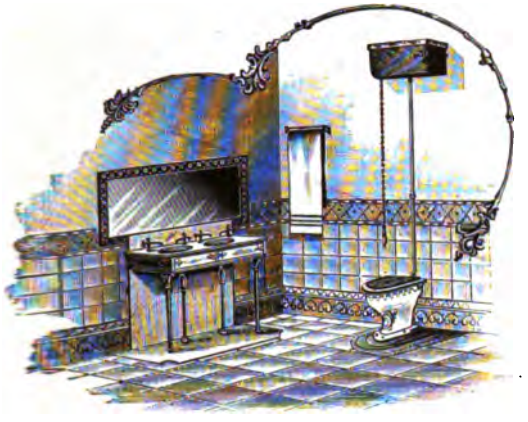
The supplement of fifty pages, upon the "Reactions of some of the Rarer Metals," is of decided importance, and is simply a continuance of the section on "The Reactions of the Metals" and of much the same character. Some of the metals have group separations outlined for them, but a general and simple scheme of analysis, which is so much needed, is not given.

A most excellent colored spectroscopic chart takes the place of a frontispiece.

As a whole the book is chiefly remarkable for the clearness, precision, and abundance of the subject-matter presented. No words are wasted. Americans will probably use the book more for reference in connection with some of our own excellent manuals than as a laboratory text-book. It should, however, be recommended to every student of qualitative analysis for his study desk.

The book is well indexed, and is clearly printed on good paper.

CHARLES LATHROP PARSONS.



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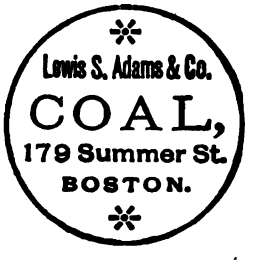

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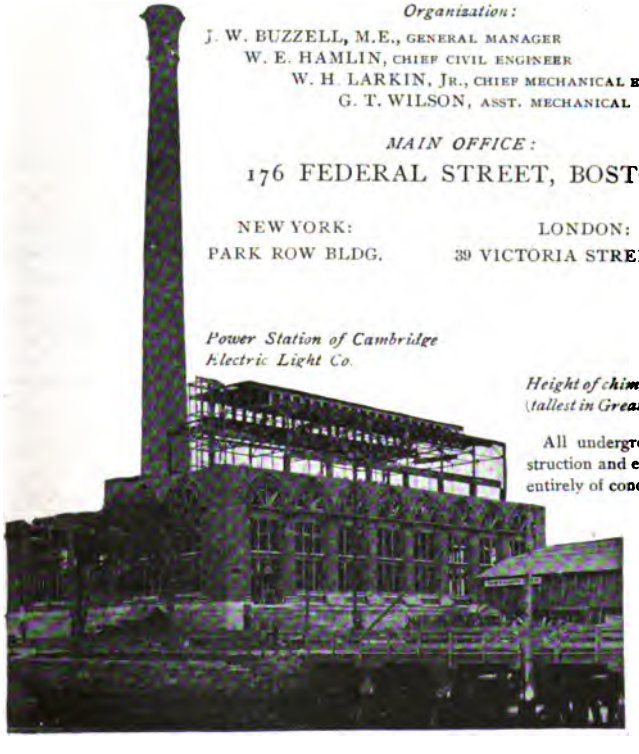

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AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Edited by ROBERT P. BIGELOW, PH D.

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REPORT UPON ENGINEERING EDUCATION.[1]

BY ELMER L. CORTHELL, C.E., D.Sc.

IT is now nearly a decade since the inception of the University of Chicago, and since I wrote an earnest letter urging the establishment of an engineering school of high order in connection with it. The efforts to establish such a school have thus far been without success.

In 1891, while making engineering examinations in Europe, I undertook to gather some information and opinions on the subject. Illness and pressing business prevented any further active efforts in this direction until the last summer and fall, when it was my good fortune to spend six or seven months on an extended professional tour for the examination of various kinds of engineering works from the north of Ireland and Scotland to Russia and Hungary. I made the best possible use of the opportunity to examine engineering schools, to confer with their professors, to talk with engineers, to obtain descriptive catalogues and the calendars of the institutions, to ascertain the different methods of engineering education in the various countries visited, and to observe, so far as I was able, the effect upon the engineering profession and its works of thorough education and the lack of it.

[1] Prepared with reference to a proposed School of Engineering at the University of Chicago.

In addition to these personal observations, inquiries and conferences, I have conducted during seven years an extensive correspondence. As chairman of the General Committee of the Engineering Congress held in Chicago in 1893, I had charge for two years of a correspondence with engineers in forty-three different countries, which led to a valuable personal or correspondence acquaintance with my profession, and this has enabled me to gain easily much information which otherwise it might have been difficult to obtain. During the last seven months I have taken up this correspondence again in order to obtain some information and views from countries which I was not able to visit.

It would be manifestly impracticable to do more than to give the very briefest digest of this mass of information. I propose to give, cursorily, the present methods of teaching engineering, taking the schools in fairly good geographical order, beginning in the north of Ireland, and going as far east on the Continent as the methods have come under my notice. In order to make comparisons with schools in the United States, I shall select two from among the many in our country for a brief review of methods there. In reference to this selection of American schools I would not have it understood that it is made because I consider these schools superior to others, but because they are fair examples of the highest order of schools in our country.

To endeavor to draw conclusions as to the best methods would require more courage, and possibly more assurance, than would be expected of a layman, particularly since the doctors in engineering differ radically among themselves, not only in regard to details, but even regarding the general character and extent of the education.

I cannot safely do more than give my recommendations as to the kind and character of school we ought to have to harmonize with the principle upon which the university was based by its founder, which, I believe, was to enable our young people to obtain in the United States the advanced education which they might need, or might desire, without being obliged to go across the ocean to find it.

With this cardinal purpose in mind, the drift of the remainder of this report will be understood, appreciated, and assented to by all.

With this brief introduction we are now ready to describe the institutions in the various countries.

IRELAND.

Three colleges, affiliated with the Royal University of Ireland, have a School of Engineering — Belfast, Galway, and Cork. The degree of Bachelor of Engineering is given, and later, not less than a year, the degree of Master of Engineering. Candidates for Bachelor of Engineering must pass five examinations, requiring four years of study, viz., the matriculation, first university, first professional, second professional, and the degree examination. The first, or matriculation, examination requires a previous preparatory course in, or knowledge of, Latin and either Greek or one of eight other languages, English language and literature, elementary mathematics, and natural philosophy. The first two examinations are identical for all students of the university, so that the beginning of the second year is the point of divergence for the professional course. There are three of these professional examinations, each in four subjects, embracing, first, mathematics, experimental physics, systematic chemistry, drawing, and descriptive architecture; second, mathematics, mathematical physics, practical chemistry, and practical engineering; and third, mathematical physics, geology including physical geography, civil engineering, and drawing. The course for the degree of Master of Engineering requires applied natural philosophy and engineering.

It will be seen from the above that engineering *per se* holds no prominent position in the course; the fact that there is only one professor of civil engineering at Belfast is confirmation of the statement.

The School of Engineering at Cork is supplied with an Adge cement-testing apparatus, a Thurston testing machine, and a thirty-ton Wicksteed testing machine.

The principle of the course seems to be to give the student a good general education and sufficient technical knowledge to make him useful as an apprentice in some prominent practicing civil engineer's office or mechanical engineering works, to which he is articled on graduation, if he is fortunate enough to find an employer.

This principle and method are illustrated in the excellent School of Engineering (Trinity College) at the University of Dublin. Here the student, in order to obtain a "License in Engineering," must have not only completed his course in the engineering school, requiring three years, but also the first two years in the course in arts. To obtain the degree of B.E. he must have not only completed the engi-

neering course, but also graduated in arts, which requires a good knowledge of Latin and Greek. The degree of M.E. requires actual practice for three years upon engineering works. An examination of this school and its methods, of which I was informed fully by one of the leading professors, and a study of the regulations and course of study led me to believe that a high order of theoretical and practical education must result. The views of the professor referred to above may be understood from the following brief memorandum from my notebook: "They do not give an engineering degree or any university degree without a course in arts, the plan being to give first a liberal education and then a professional education, considering it wisest to give the young man for his life work the breadth and scope and intellectual grasp that can only come from a liberal education with its mental training."

The Royal School of Science for Ireland is also located in Dublin, and is under the department of science and art, South Kensington, which has undertaken the management of several technical and industrial schools in Great Britain.

Scotland.

At Dundee is *University College*, a part of St. Andrew's University. It has a department of engineering, well equipped with modern appliances and everything required for research and experiment. Three years of study in engineering and science are required for the degree of B.Sc. in engineering, which is given by the university. A thorough course of study, with apparatus for experiments and illustrations, a steam engine of 75 H. P., a gas engine of 10 H. P., a high-pressure tubular boiler, various testing machines (one testing up to fifty tons) and a number of appliances for experimental work, with dynamos, electric machines, and an extensive apparatus for electrical laboratory work, all place this excellent school in a high rank among the engineering schools of Great Britain. One advantage, which would not appear if the engineering school alone is spoken of, is the teaching of allied sciences in the Dundee college — chemistry, mathematics, and natural philosophy, including mechanics, kinetics, hydrostatics, optics, thermodynamics, magnetism, and electricity. Electrical engineering is taught in connection with this science department. Instruction in all these physical sciences of the university is fully supplemented by well-equipped laboratories.

The *University of Edinburgh* is giving more attention than formerly to engineering education. Seven years ago, when I made my first examination into this subject in Europe, the beginnings of a "plant" were being installed, boiler, engine, etc. The engineering department is now well advanced in these facilities. It is, however, uphill work to obtain the costly apparatus required to keep abreast of the times in appliances used in other countries, on account of the great difficulty in obtaining the means to furnish adequately the department with what it needs; in fact, this is the keenly felt want almost anywhere in Great Britain, as it is in the United States. On the Continent it is different, for the State takes a paternal and active, and generally controlling, interest in education, particularly technical and industrial education, as we shall see further on.

There are four faculties in the Edinburgh University — arts, law, medicine, and divinity. The science features are included in arts, and there is, of course, the department of engineering, its object being the practical application of the scientific studies to the various branches of engineering. The course is two years. The university confers the degrees of Bachelor and Doctor of Science.

The *University of Glasgow* will celebrate its four hundred and fiftieth anniversary in 1900, for in 1450 it was founded by Pope Nicholas V. In 1840 Queen Victoria founded a special chair of civil engineering and mechanics. The engineers of whose lives and usefulness Samuel Smiles has told the world had already left their impress. Telford, Smeaton, Stephenson, Brunel, and many other remarkable men had founded a new profession, which before the end of the nineteenth century was destined to take rank with the learned professions. There are four courses to obtain the degree of B.Sc.: civil engineering, chemical and mining engineering, mechanical and electrical engineering, and naval architecture and marine engineering. The courses of study are arranged accordingly, though as published by Professor Rankine, in 1865, they are not intended in any way to compete "with the offices of civil engineers," where the young men were taught practical engineering.

There is now a chair of naval architecture, the occupant of it being the distinguished naval architect, Professor J. H. Biles.

The University of Glasgow proposes to the student of engineering a complete general or liberal education as a necessary feature; evidently for

the purpose of sending out strong, able men with an education, broad not only in science, but in humanities as well. Its latest requirements for obtaining the degree of Bachelor of Science in Engineering, that of the present year, 1897–98, compel a successful preliminary examination in arts, — English, Latin or Greek, mathematics, and one of the following modern languages, French, German or Italian. The details of the required knowledge in each show that no smattering of any of them will avail the candidate; he must have a thorough as well as extensive knowledge of each subject, and in mathematics the student must pass in dynamics as well, including kinematics, kinetics, statics, and hydrostatics.

Of course an actually earned degree in arts and sciences in any of the universities of the United Kingdom is equivalent to a successful examination.

I have given special prominence to Glasgow University, as it is one of the four that demand an advanced preliminary education in liberal studies, and because from personal conference I am sure it has as high an aim and as wide a scope in its education of engineers as can be found anywhere, although it may content itself with less practical teaching of engineering, in laboratory and workshops, than we will find elsewhere as we go on with the description of the various schools of Europe.

It is evident, however, that with such requirements for admission to its engineering department, and with at least three years required in that department to obtain the degree of Bachelor of Science in Engineering, the most complete and thorough education is certain to result.

England.

The Durham College of Science, at Newcastle-upon-Tyne, is one of the most progressive, earnest, and practical schools in Europe. It could hardly be otherwise, located as it is in that great hive of industry, where, from the great Armstrong works down to the minor manufactories of various kinds, almost every branch of constructive engineering work is carried on, a section of country growing with great rapidity in commerce, industry, and population.

The college forms an important part of the University of the North of England. In all the natural sciences and all departments of engineering the instruction is complete and practical. The laboratories,

chemical, physical and engineering, are well supplied with all necessary facilities for thorough examinations and research. Students to be admitted must be sixteen years old.

The course in all branches of engineering and naval architecture extends over three years; students can then be examined for the degree of B.Sc., two years afterwards for M.Sc., and not less than seven years after that for Dr.Sc., providing they have reached the age of thirty years.

There is a preliminary examination in arts for graduation in science, or there must be shown by the candidates in lieu of it a certificate of graduation in arts at one of the several universities of high rank, including Oxford, Cambridge, Edinburgh, Glasgow, Dublin, McGill College (Montreal), and some colleges and universities of the colonies, or they must show a certificate of having passed the examination for the degree of B.Litt. in the University of Durham.

This preliminary examination assumes a fairly good general education, as will be seen from the requirements for March and September of the past year. Candidates must pass at the same examination in four of the following subjects, of which two at least shall be languages: 1. Xenophon's "Anabasis," Book I. 2. Cicero, "de Amicitia." 3. Souvestre, "Le Philosophe sous les Toits." 4. Hauff, "Die Karavine." 5. Mechanics, hydrostatics, and pneumatics. 6. Euclid, Books IV and VI. 7. English history, William I to Henry II. 8. Geometrical optics. 9. Logic. The subjects of the examinations at the end of each of the three years show that a most comprehensive scientific and engineering knowledge is required.

The engineering laboratory is worthy of detailed mention, as it has some excellent and one, at least, very remarkable engine for experimental purposes. This is a vertical, quadruple expansion, surface condensing steam engine, with four separate cranks, working it up to 200 H. P. — really separate engines, for they can be worked single, double, triple or quadruple expansion at any degree of expansion in each cylinder, with various ratios of cylinders and receivers, various angles of cranks, with or without jackets with steam pressures up to 210 pounds per square inch. A specially designed hydraulic dynamometer is fitted to it and arranged with gear for autographically reading the effective work transmitted through the shaft; it also has all the necessary arrangements for measuring the water — feed, circulatory, and condensed — in jackets, cylinders, and steam chests. This complete ex-

perimental engine was designed by the professor of engineering, R. L. Weighton. One of the remarkable incidents about its construction was, that the plans for separate parts were given to forty-six different manufacturing concerns, and when it was assembled and put together into working shape at the college every part fitted its place perfectly.

There are also horizontal coupled compound steam engines, gas engines, compound Parsons turbine motor and dynamo, testing apparatus of many kinds, machine tools, drills, planes, lathes, etc. The course in this laboratory extends over the three entire years. It is intended to serve two purposes: one to give practical demonstration of the subject-matter of the studies, and the other to provide means for original research for the senior students in various fields of engineering practice. "It is not at all intended as a school for teaching the use of tools, except in so far as this may be acquired incidentally." In fact, the personally expressed opinion of Professor Weighton, who is a practical steam engineer of extensive practice, was decidedly opposed to the method of teaching the use of machines and requiring or permitting the pupils to do work in the school. If they do this, as they go on with the theory they have little appreciation of the work and look upon it as so much recreation and play. He advises the boys to have two years in a shop before they come to the school, then they realize how valuable the theory is going to be to them and do not waste their time. The school has an arrangement with good establishments in the vicinity, where the students can work from Easter to the fall term. In reference to this quite important question, some experience by the Armstrongs is of value. Industrial schools were established by this company at their works to teach boys practical mechanical engineering. The foremen and superintendents of the works taught them, and they did exceedingly well and the project was a success; but the school was turned over to the South Kensington management and the "scientific" professors took charge. It failed from that moment, as the foremen and superintendents were unwilling to teach under their control. They are of the opinion at those works, and from this experiment, that if the boys are to be taught to do actual work it should be done under practical mechanics, and they are of the further opinion that the teaching of machinery work in the schools is a mistake.

Yorkshire College, Leeds. This is one of the colleges of Victoria University; two other colleges are included, University College, Liverpool, and Owens College, Manchester. The requirements for admission to the engineering department is the same in all, which is to pass the Victoria preliminary examination, or present certificates of graduation from other well-known universities in Great Britain. This "preliminary" is practically the examination in the Victoria University at the end of the first year of study, and it embraces English language and history, geography, pure mathematics, and three of the following subjects, one of which must be a language — Greek, Latin, French, German, elementary mechanics, chemistry, and physiology.

The engineering department is not large, as the extent of facilities in the laboratory is limited to sixty students. Notwithstanding its limited numbers, it deserves a prominent place in any category of engineering schools on account of the character of the laboratory facilities, the methods of teaching, and the practicability of its work. The principal professor is Mr. John Goodman, an engineer of twelve years' practice, and thoroughly informed by personal examinations as to the best schools in the United States, Canada, and the Continent; his views and his system of teaching are worthy of some notice here.

The principle underlying the method is that "the scientific training at the college must be regarded as a means of acquiring principles that underlie the art of engineering, and the training in the works as necessary for acquiring the art itself." Which remark, taken from the Calendar of 1897, refers mainly, no doubt, to mechanical engineering. The work in the laboratory consists chiefly of making experiments and testing, and it is definitely understood that "no instruction is given in the use of either hand or machine tools." It is suggested that it would be very well for students before entering the college to have some practical experience in engineering works. The courses of study and the subjects taken up, both in civil and mechanical engineering, cover the whole ground and go to the extent required in any college of engineering, the last of the three years being devoted to the constructive work which the students are to enter upon on graduation.

In mechanical engineering an excellent feature is the illustration of the subjects by an arc light lantern, which is switched on at a moment's notice and used in broad daylight. There are at hand, convenient for this purpose, over 2,000 lantern slides. As it would require too much time for the student to sketch in his notebook from these

views, duplicates of them in photographs, about 2½ inches square, are given out for pasting into the "final copy" notebooks. Skeleton diagrams, taken from the blackboard illustrations, are sketched in the notebooks by the side of the prints. They cost the college a little over one cent each.

The laboratory work is an important feature of the course; two days per week are given to it, and work there is intended to illustrate the lectures and to be done concurrently with them. The experiments are on full-sized work, not "toy" experiments. The 100-ton Buchton testing machine actually tests full-sized bridge ties, struts, columns, rolled joists, girders, rails, chains, ropes, etc.

A lighter testing machine is used for tension, torsion, and bending; another for studying effects of repeated loads on materials; a wire testing machine is provided; also the usual experimental and fully equipped steam engines; an actual Warren girder, 14 feet span, for ascertaining deflections under load; hydraulic appliances; centrifugal pump, lifting 75,000 gallons per hour; Pelton wheel; meter; weirs; etc.

As to examinations, Professor Goodman, in the discussion of a paper by Professor George F. Swain, Massachusetts Institute of Technology, read before the Engineering Congress held at Chicago in 1893, on "Comparison between American and European Methods in Engineering Education," gave his method at Leeds. At the end of the first year he gives the men a problem of some actual work to carry out, and a week in which to do it; when the paper comes in the student certifies that he has had no assistance whatever, and presents full notes of his process. At the end of the second year he gives a set of problems and allows them to use their own notebooks, just as they would do in after life. At the end of the third year an ordinary examination is held and it is done in the ordinary way, a certain number of questions are given and sufficient time is allowed, generally a whole day, in which to answer them.

It is a question whether large available funds for the purchase of workshop, tools, and machinery in this and other schools of Great Britain would not lead to the use of tools and to actual work; that is, if they had the means to do what is done in the Massachusetts Institute of Technology, or Sibley College, Cornell University, would it not be done? To attempt it, however, unprovided with full shop facilities, which nearly all the colleges in Great Britain lack, would, in the opinion of Professor Goodman, be useless and a waste of time.

I believe from the pronounced opinion on this subject by several able educators they disbelieve in that method of teaching, and had they extensive laboratories they would still teach as they do, very much as we shall see it done at Zürich, Switzerland, where we find the finest laboratories in the world.

University College, Liverpool. The well-known Professor H. S. Bele-Shaw is in charge of the engineering department. We are met at once with a near approach to the methods found in some of the largest schools in the United States.

In addition to the usual feature of engineering schools of supplementing the ordinary professional training by systematic technical teaching, with the usual lecture halls, museum, class rooms, and drawing rooms, it has a large laboratory and workshop, where we find various engines, testing machines, and machine tools, "enabling the students to combine practical and theoretical teaching," "the application of scientific principles to practice."

As the same general preliminary instructions and training as in practice is required of all students preparing for any department of engineering, the first two years is practically the same for all. In the third year they specialize in some particular branch.

The same feature prevails here that is found in all British schools and is still observed in after practice, viz.: apprenticeship and pupilage, where the young man becomes an "articled pupil" or "apprentice" in some civil engineer's office, or in some engineering construction works. The course, as usual, extends over three years.

The definite purpose of teaching the use of tools is brought out in the Calendar:

> In the first year students spend four hours in the Woodworking Department, and before proceeding to actual pattern-making are required to do, satisfactorily, a certain number of exercises at the bench and lathe. Seven hours per week are spent in the main workshop at the vise, lathe, and other tools, the object in view being to impart an acquaintance with the use of tools, and some idea of working to a drawing.
>
> Students in the second year are required to spend one afternoon at pattern-making, two mornings in the main workshop, and one morning in the testing department. They are allowed to prepare test pieces and experimental apparatus for their own use. Students in mechanical engineering (second year) take a special course of workshop practice instead of surveying during the summer term.
>
> Students in the third year go through a series of steam engine trials on the experimental steam engines, gas engines, and other motors, in the laboratory, thoroughly working out all results. In addition to this, experiments on larger engines

are undertaken, with the kind permission of users of power in the neighborhood. A course of experiments on hydraulics is arranged, and also a further course of the testing of materials. The testing machines and workshops are available for carrying out experimental research.

That the college is prepared to carry out this program is shown by the list of machine tools in the workshop, which as one item comprises fifteen lathes for metal work and ten for wood work, with other machines of various kinds for actual work.

The proposition has recently been urged to establish here in this great center of commerce a chair of naval architecture, as at the two great centers of shipbuilding, Glasgow and Newcastle-upon-Tyne.

Owens College, Manchester. This college was founded in 1846 by Mr. John Owen, a Manchester merchant. In 1880 the Victoria University was created with this as its first college, since which date the Liverpool College and Yorkshire College, Leeds, have been admitted as sister colleges.

The college comprises all departments of education and has a special department of engineering, the head professor and director of which is the able Professor Osborne Reynolds. Students on entrance to any departments of the college must be sixteen years of age. It is expected of the student of engineering that he has acquired, prior to entrance, the knowledge needed for the preliminary examination of the Victoria University referred to above.

Here, as at Leeds, the instruction "is not intended to supersede the practical training, which can only be obtained at the office of a civil, or the workshop of a mechanical, engineer." Attendance on a full course of three years is expected of candidates for the Certificate in Engineering.

A laboratory course is considered necessary to complete the education of an engineer, whether mechanical or civil. The making of tests, both for materials and machines, and a reduction of the results are considered an important part of an engineer's work; the training necessary for making these tests is essentially scientific, familiarizing the student with practical mechanics in their higher developments, and by actual examples gives this training a reality, which the present and future development of engineering requires in the engineer. Such are the announced reasons for the laboratory work. From a personal examination of the laboratory in 1891 and 1897, I am satisfied that it combines all that is necessary to carry out the objects above stated.

Department of Engineering in Oxford and Cambridge Universities. Both of these departments are of comparatively recent establishment. Both are provided with the necessary engines and machines for testing in civil and mechanical engineering. At Cambridge there are workshops with lathes and planing, shaping and slotting machines, as well as a forge and other appliances.

There is a staff of skilled workmen to give instruction in each branch of the work. These shops are on quite an extensive scale, but it is understood that the work in them is not intended to take the place of pupilage in a large establishment, but to reduce the time of such pupilage by going into it with a fair knowledge of the use of tools.

The Royal Indian Engineering College, Cooper's Hill, London. This is not only an important and well-equipped engineering institution for the higher technical instruction, but it has developed from very interesting conditions. Its history illustrates fully the state of engineering education at the time of its establishment, not yet thirty years ago, from the fact mainly that it was at that time impracticable to find young men in Great Britain with sufficient technical engineering knowledge and training to take up the Indian work; hence the necessity of establishing this school.

The college is not large in membership, only fifty being admitted annually, its purpose being specially for the preparation of engineers for Indian positions, but it has a very complete curriculum. Candidates for entrance must be between seventeen and twenty-one years of age, the maximum being fixed on account of climatic reasons, older men being more liable to illness in the hot climate of India and less responsive to acclimatization.

The students at entrance must have a good general education, as well as in elementary mathematics, comprising arithmetic, elementary algebra, geometry to the sixth book of Euclid, elementary mensuration, and plane trigonometry and the use of logarithms; the general education must include some classical or modern language.

The course occupies three years; French or German is one of the studies, with more purely engineering studies. Before the graduates can take positions in India, they must go through a course of practical engineering for about a year under a professional engineer.

City and Guilds of London Institute for the Advancement of Technical Education. The institute has two schools, the Central Technical College and the Technical College in Finsbury, both within the limits of London. We will have principally to do with the former. It is an important institution, both in respect to the scope of its work and its high educational character.

It is now about twenty years since quite a number of the Guilds or "Livery" companies of London undertook to meet the new conditions which the rapidly advancing state of modern manufactures required in the character of the workmen to enable Great Britain to keep pace with other countries. Large and accumulating sums were in their hands, bequeathed from former generations. From these they could draw what amount might become necessary to generally improve the industries of the country by improving its technical education.

They wisely referred the project, as to its scheme, to several distinguished men of science and engineers, and obtained a valuable set of reports upon the best means of accomplishing the purpose in view. While the scheme was comprehensive, and combined several minor or auxiliary means of industrial education, the main feature of it was the foundation of the Central Institution for higher technical instruction.

The general features are as follows: Students must be seventeen years of age. The course covers three years. The requirements for admission are a satisfactory examination in elementary mathematics, mechanics, mechanical drawing, physics, chemistry, and either French or German. The first year's course is the same for all students, and is intended to give a thorough preparation for the special technical studies of the second and third years; mathematics is given an important place in the first year, as it is believed to be impossible to attain a high place as a scientific engineer in either of the three departments without a good knowledge of mathematics. These departments are engineering, physical science, and chemistry. The first comprises mainly civil and mechanical engineering, the second chiefly electrical technology, the third the preparation of the student for the higher posts in chemical industries.

The building and its equipment deserve more extended mention than can be given here. I cannot speak too highly of these admirable arrangements. I have examined it twice, once in 1891 and again in 1897, each time in the company of Professor W. C. Unwin, the head professor of engineering. The descriptive and illustrated printed matter

before me covers nearly two hundred pages. The voluminous notes in my journal show my own high appreciation of the school, its methods, its appointments, appliances, and its very able staff of teachers, several of them being men of international reputation.

The building is five stories high. The engineering workshops, laboratories, smithy, dynamo room, dynamo and motor testing room, the physical and mechanical laboratories, and joiners' shop are in the basement. The ground floor is devoted to class rooms and professors' offices. On the first floor is a large reading room, library, and also the physical laboratories and the administrative offices. On the second floor is an extensive museum of engineering, mathematical and physical models, and also the large chemical laboratories. On the third floor is the engineering drawing room, 55 x 67 feet, the remainder being devoted mostly to chemical laboratories.

The mathematical department is thoroughly provided with all the necessary facilities and laboratories for a complete instruction in this very important fundamental study. In the engineering department is a completely fitted up workshop and laboratory. Instruction is given in the former in the use of tools, the idea being mainly to give the student some practical acquaintance with machine tools and the methods of manufacture, so that when he reaches the actual works, if he is to be a mechanical engineer, he will not be so much at a loss to handle himself as he would be without such previous acquaintance with shop work. In this laboratory is a complete outfit of every sort of testing apparatus, from a 100-ton Wicksteed testing machine to a complete set of various kinds of micrometers.

The course of civil engineering is also very complete, but it is considered necessary for these students to have, to a certain extent, a fair knowledge of mechanics, mechanical engineering, and electricity and electrical engineering.

The physical department, under the well-known Professor W. E. Ayrton, is specially devoted to electricity, which is very practically taught and illustrated in the laboratories. These are upon an unusually extensive scale. There are three electrical research laboratories, a dynamo room and a laboratory for testing dynamos and motors; and five distinct laboratories: the junior electrical, the heat, optical, magnetic, and acoustic laboratories, each arranged for making extensive series of organized experiments. The electrical engineering course embraces practical physics, electrical technology, and advanced electrical technology.

From the first day of his course the student learns to make actual measurements in the laboratories. When he has completed his first year he is thoroughly grounded in the science, and has about mastered the basis of the exact measurements of electrical quantities.

The student of electrical engineering in the second year must work several hours of the week at engineering designing and in the engineering workshop, both under Professor Unwin, and several hours also at mechanics and mathematics under Professor Henrici, of that department; on the other hand, mechanical engineering students must give considerable time to electrical technology, for the reason that the use of electrical apparatus in mechanical engineering is rapidly growing.

The chemical department, under Professor H. E. Armstrong, like the other departments, serves a double purpose: it trains specialists, that is, technical chemists and chemical engineers, and gives important and necessary instruction in chemistry to students of the other departments.

Here, also, the student is at once set at work solving definite problems requiring thought and close investigation. The principal object of the course of study is to train young men in the methods of chemical research, so that they may learn to work with independence, for in this way alone can they improve and extend the industries of which they will be later called to take charge.

The intermingling and correlation of the departments are well illustrated by the following course taken from the program for 1897.

GENERAL DISTRIBUTION OF TIME.

The following table shows the weekly distribution of time for all matriculated students of the Central Technical College:

FIRST YEAR.

For Students of any Department:

Mathematics	9 hours
Engineering	7 "
Physics	7 "
Chemistry	7 "

SECOND YEAR.

For Engineering Students:

Mathematics	9 hours
Engineering	12 "
Physics	5½ "
Chemistry	3½ "

For Physical Students:

Mathematics	8	hours
Engineering	10	"
Physics	10	"
Chemistry	2	"

For Chemical Students:

Engineering	10	hours
Chemistry	17	"
Crystallography	3	"

THIRD YEAR.

There will be mathematics from 10 to 12 on Monday and Wednesday for Engineering and Physical students. Also one day per week in the winter term will be taken in a selected department. The rest of the time is given to the work of the department to which the student belongs.

Some important features of this institution appear in a recent report of a special committee appointed by the governors of the guilds, which was instructed to make a full inquiry into the expenditures and the results attained by the institution.

This committee was composed of men of high reputation and great experience. Incidentally, the number of students, as appears from this report, is 210.

The subcommittee reporting on the educational work of the institute approve of the methods, especially of the principle of research work.

As to expenditures, the committee made a careful and comprehensive investigation in the way of comparison with other schools of high standing in the United States and on the Continent, with the result that they found the gross cost per student less here than elsewhere.

They concluded that this institution supplies the highest form of technical education in London, and that its work is of university rank.

It will be noticed in the above account of the Central Institution that no mention is made of mining engineering. The absence of this special department is due, not to the want of appreciation of its importance, but to the fact that it is made a specialty in an excellent institution across the street, the Royal College of Science, with which is incorporated the School of Mines.

This college is supported by the government, and its purpose is to furnish systematic instruction in the general principles of all the branches of physical science to students.

The School of Mines is incorporated with it, the students obtaining their scientific knowledge and training in the principal institution and their special knowledge of mining in the special school, where separate classes are formed for the purpose.

To the general course of study in the College of Science the mining department adds instruction in determinative mineralogy, metallurgy, assaying, and mining operations.

There are two other important engineering schools in London, both well equipped with apparatus for teaching. One of these is a department of the University College, and the other of King's College. In a full account of all such institutions these would have a prominent place.

In the former there is an unrestricted admission of students without examination, and to any class or classes they may select. The complete course extends over three years, but if a student cannot (or thinks he cannot) devote more than two years to study he is accommodated by a special plan, and under it a very large number finish their education in the two years. The study of any modern language is not obligatory.

The same remarks about absence of matriculation examination and freedom to take the whole or part of the course apply to King's College.

The Central Technical College has been given here the more prominent position among these schools, as it is not only a distinctively engineering school, but is the best example of such a school in London.

France.

The methods of engineering education in France cannot easily be compared with those in Great Britain or the United States. As will be seen by the following description, the schools of the highest grade are purely government institutions, graduating government officials, as do our schools at West Point and Annapolis, with this difference, that none but military and naval officers are graduated at our schools, while the most accomplished graduates at the French government schools are educated entirely in civil engineering and become government civil engineers. At West Point the most accomplished graduates, educated almost entirely in military matters, become immediately civil engineers and are placed in charge of all the extensive works of rivers and harbors which, in the United States as in France, are under the control of the general government.

There are three classes of schools in France that graduate civil engineers: first, the Government Schools, a polytechnic school, followed by the *École des Ponts et Chaussées* and *École des Mines;* second, Central School of Arts and Manufactures; third, Industrial Schools.

First: *Government Schools.* These furnish the government with engineers, and have done so for many years. They have also a class of students who graduate as "*élèves externes*" (outside graduates), and they may be French or of any other nationality. Many prominent French engineers have graduated as such, and so have many United States engineers. No doubt these schools, in scope and character of the education given, are equal to any in the world, as is attested by the high order of the engineers who have graduated there.

The regular French students who are able to enter these schools (the number is extremely limited and in accordance with the necessities of the government as to filling up the positions in the service — civil, military, and naval) are admitted after thorough and severe examination. The best university graduates (who have had a course in arts, Latin and Greek) endeavor to enter this school; they are from nineteen to twenty-one years of age. The number of competitors for about two hundred annual admissions varies from 1,000 to 1,800. This gives a first selection of the highest talent and fitness. Of this two hundred, only about twenty (the best pupils) are finally admitted to the engineering schools; the rest of the graduates of the polytechnic school become military or naval officers, with whom we have here nothing to do except to say that after their two years in the polytechnic school they study two years at the military *École d'Application de Fontainebleau,* in the naval school, or in the school of naval architecture. The twenty students above mentioned enter, from the polytechnic, either the *École des Ponts et Chaussées* or *École des Mines,* where the course occupies three years.

It is this *École des Ponts et Chaussées* with which we have most to do in this discussion, and which I will further allude to after saying that the "second" school, Central School of Arts and Manufactures, is made up of those who either were unable to enter the government school or have not attempted to do so. This school is of a high order, however, but not equal to the government polytechnic, and its course covers three years instead of five years. The graduates of this school cannot be admitted to government service, but enter into private practice.

The "third" class of schools is mainly industrial, and their graduates become superintendents, foremen, and mechanics.

Referring now to the twenty students annually admitted into the *Ponts et Chaussées* and *Mines*, they are, from their entrance into this branch of the polytechnic school, government officials, paid as such and invariably given, on graduation, government positions for life. When they graduate from this final school they are usually about twenty-five years of age, and have, of course, a most complete education.

The *École des Ponts et Chaussées* is so well known and has such a high international reputation that it is unnecessary to occupy much time with it. Possibly, however, it will serve to show the scope of the education to simply give the courses of study, bearing in mind that this school is really a school of application, after what would be considered a good engineering course in the United States.

COURSES OF THE ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES.

I.	Applied mechanics: strength of materials
II.	Applied mechanics: hydraulics
III.	Mineralogy and geology
IV.	Constructive materials (technical study and tests)
V.	Routes, locations
VI.	General methods of construction
VII.	Bridge construction
VIII.	Internal navigation
IX.	Maritime works
X.	Railroads
XI.	City and country hydraulics and irrigation engineering
XII.	Steam engines
XIII.	Applied electricity
XIV.	Architecture
XV.	Administrative law
XVI.	Political economy
XVII.	Fortification
XVIII.	Constructive drawings and sketches of railroads, buildings, and machines
XIX.	German language
XX.	English language
XXI.	Photography
XXII.	Fish culture and fishing

Some of these courses may seem to be outside the domain of civil engineering, such as administrative law and political economy, but the details of these courses show that the instruction in them is for the purpose of giving the student that special knowledge of these subjects which he needs in the administration of his engineering works — con-

struction, maintenance, and operation. Thus the railroad course does not confine itself simply to the construction of railroads, but goes into the operation in all its multifarious practical details of organization and handling of the property and the commercial and financial features.

As these government engineers may in war be military engineers, they receive instruction in military engineering and tactics, though this is a subsidiary feature of their education.

Speaking generally of this admirable French school, it would be difficult to find in any country any civil engineering school that surpasses, possibly equals it, in scope, extent, thoroughness, and completeness.

SPAIN.

A recent correspondence to ascertain the present methods has placed in my hands about three hundred and fifty pages of printed matter, giving the requirements of admission to the government *Escuela Especial de Ingenieros de Caminos, Canales y Puertos* (Special School of Engineers of Roads, Canals, and Ports) at Madrid, the regulation of this school and the detailed programs of the various departments.

The high character of the school will be seen from the fact that the preparatory course for it should occupy four years and its own course is five years.

A careful examination of the results of the programs and a fairly good acquaintance with some of the leading engineers of Spain convince me that this school, in scope and thoroughness, ranks with any in the world.

The requirements proven by a rigid examination are, first, an age of at least sixteen years. To have the degree of Bachelor of Arts, or, being less than twenty-five years of age, to pass easily in the following: elementary arithmetic and algebra, plane and spherical geometry and trigonometry, higher algebra, analytical geometry, descriptive geometry and its application to shades and shadows and to perspective, calculus, lineal, figure, and ornamental drawing and shading, French and English language.

From this course, which the head professor of the school has kindly given me in manuscript, it is clearly seen that the school keeps pace with the modern and most recent advances in applied physics, mechanics, and electricity.

The intention, no doubt realized, is evidently to give the engineer

that broad and extended and thorough education which will fit him for the highest duties which he may be called to meet by the requirements of the present day.

Belgium.

Referring to the methods of engineering education in France and Spain it will be seen that continental methods are radically different from those in Great Britain and the United States. This difference is principally due to greater paternal control. The governments own and operate the water and the rail communications; even if there be any private ownership of railroads the general management must be more or less under governmental control. Government railroads and government waterways must not be subjected to the ruinous competition of unrestricted economical operation by individuals. Consequently the public pay for the water and rail facilities maintained, owned, and operated by the government, and also (and what is the great objectionable feature of state ownership of railroads) the enhanced cost of non-competitive transportation.

The State must have its own agents to build, maintain, improve, and operate its ways of communication, and consequently it undertakes to raise up men for the work by a most thorough and careful method of education, with the purpose, also, of making these officials, in at least the higher positions of service and responsibility, equal in ability to other higher officials of the government, so that they may, by the sheer force of the trained intellect, give the government the most efficient service possible.

While the government universities and special schools are open to all students who choose to avail themselves of the teaching facilities and pay for them, it recruits its servants out of the highest grades.

In Belgium there are two government schools of engineering, one an integral part of the University of Ghent and the other of that of Liege. There are also two other schools connected with nongovernmental universities, Brussels and Louvain. Until within the last five years all engineers on government works had to be graduates of the two government schools, but on the urgent demand of the two latter universities to allow their engineering graduates to compete on equal terms and without prejudice with the graduates of government schools, the State yielded. Now all four schools have an equal chance in these competitions.

It is significant of the high character of the government schools that up to the present time the graduates of the two private schools have not succeeded in bearing off any of these coveted prizes.

In order to understand more fully and appreciate the difference between English and continental engineering education it should be stated here, with the intention of referring to the subject again later on, that in Belgium, and generally elsewhere on the Continent, the principal and controlling purpose in methods is to give the student of engineering a thorough liberal and scientific education, with laboratory facilities for experimental work by the students, both in chemistry and physics and in the use of models, preferring to leave the manual training to his future work, if it is to be of such a character as to require the use of hand and machine tools. He must first be given a liberal and professional scientific education as the foundation for his life as a man, a citizen, and an engineer. The engineers, teachers, and those who direct the methods of education are not in accord with the general English practice.

From the Catalogue for 1897 of the engineering school of the University of Gand (Ghent), and from conference with some of its graduates, now eminent civil engineers, I will give a brief abstract of the requirements and methods. The methods in the universities and schools referred to do not greatly differ.

There are two engineering schools annexed to the University of Gand, the School of Civil Engineering and the School of Arts and Manufactures. The former comprises the following grades: grade of Legal Engineer of Civil Construction, Civil Engineer, Engineer Architect, and Civil Conductor. The latter school has the following grades: Mechanical Engineer, Chemical Engineer, and Industrial Engineer. Each of these two schools is divided into a preparatory school and a special school.

The graduates of the highest grade, first mentioned, may take part in the competition for recruiting the Engineer Corps of *Ponts et Chaussées*, the Corps of Railroad Engineers, and the State Telegraph Engineers. Graduates of all the other grades of both schools can obtain the diploma of electrical engineer after a year of study in the Electro-Technic Institute of Montefiore.

The director of both schools is the administrative inspector of the university. Under him are two inspectors, one of the preparatory and

the other of the special schools. The professors have nothing to do with the general or detailed arrangement of instruction. The director, upon the report of the inspectors of studies, arranges the order of the studies, and the inspectors attend to the execution.

The time required for the highest grades is five years, two preparatory and three special, also for the engineer architects; all the others require four years, two of each, except the civil conductors, which take a two years' course.

The detailed programs of the courses of study are decided upon by the Minister of the Interior and of Instruction, on the proposition of the director of the schools, assisted by the professors.

There is an harmonious arrangement of the studies of the entire scheme to accomplish the purpose in view, viz.: the most complete preparation for the special professional work of each student when he enters upon his life work. The students are not confined to lectures, text-books, and examinations. They engage in graphical works, practical exercises, and scientific excursions and visits to industrial establishments with the teachers, and to works under construction.

The examinations required for admission to the preparatory schools show at once that a high order of education is demanded. To be admitted, the applicant must creditably pass in ten subjects. He must be well up in three languages, his own and two others, a very complete acquaintance with history and geography, of arithmetic, algebra, geometry, plane and spherical trigonometry, analytical geometry to two dimensions, descriptive geometry and design.

The examinations of the three years which students must creditably pass to accomplish the grade of engineer of civil construction are as follows:

FIRST EXAMINATION.

1. Constructions of Civil Engineering
2. Hydraulics
3. Calculations of the Effect of Machines
4. Descriptions of Machines
5. Topography
6. History of Architecture
7. Industrial Chemistry
8. Industrial Physics
9. Political Economy
10. Exercises and problems, practical works

SECOND EXAMINATION.

1. Civil Engineering Construction (2d part)
2. Stability of Constructions
3. Description of Machines
4. Construction of Machines
5. Technology of Elementary Professions
6. Administrative Law
7. Civil Architecture
8. Mineralogy
9. Exercises and problems, practical work

THIRD EXAMINATION.

1. Civil Engineering Construction (3d part)
2. Stability of Construction
3. Application of Machines
4. Railroad Operation
5. Electricity and its industrial application
6. Geology and the Elements of Palæontology
7. Civil Architecture
8. Exercises and problems, practical works

These examination requirements are given entire, as they are characteristic of continental courses of study for professional civil engineers. The varied character and scope of the education will be seen and appreciated; while the grades of somewhat lesser rank do not cover quite so much ground, they are all extended and of wide scope, as will be seen by one more illustration of a course, that of industrial engineer, two years in the preparatory school and the following in the special school, covering also two years.

GRADE OF INDUSTRIAL ENGINEER.

1. Industrial Mechanics (1st part), comprising the calculus of the effect of machines
2. Description of Machines (1st part)
3. Description of Machines (2d part)
4. Analytical Chemistry
5. Architecture
6. Industrial Chemistry
7. Industrial Constructions
8. Problems, sketches, applications, and exercises relative to Nos. 1, 2 and 3, problems of industrial construction
9. Exercises in architecture and problems relative to Industrial Chemistry
10. Laboratory work, visits to manufactories

SECOND EXAMINATION.

1. Construction of Machines
2. Technology of Textile Materials
3. Technology of Elementary Professions
4. Sketches of plans and surveys (part of the topographical course)
5. Industrial Physics
6. Use of Machines
7. Electricity and its industrial uses
8. Political Economy
9. Commercial Geography
10. Problems relative to mechanical construction workshop practice
11. Problems of construction relative to Chemical Arts and to Nos. 2, 3, 5 and 7
12. Laboratory work, visits to manufactories

These various studies are not entered into in a perfunctory or formal manner. There is earnest, thorough, and extended work, both on the part of the teachers and the pupils. These pupils are not lads, but young men old enough to appreciate the necessity for hard work. They are university students, really postgraduates. This will be seen from the fact that, to enter the preparatory school, a six-year course of study in the "humanities" is required and a degree certified to, if the applicant wishes to enter without the rigid examinations already described. These schools are purely civil, and teach no military science as they do in France.

In Holland the education of engineers is carried as far and as systematically as in Belgium. The program of studies in the excellent Royal Institution at Delft, for the year 1897–98, compares very favorably with that of Gand, above analyzed. It embraces the same general courses of study, and requires about twenty professors and fifteen assistants.

SWITZERLAND.

In reference to Switzerland, the whole process of general and special education needs to be stated, but my space will not permit. It may be asserted without fear of contradiction that it is the best educated country in the world. There are no illiterate people, certainly not enough to form a class, and it is contended by leading Swiss educators that not one can be found who cannot read and write except he be of unsound mind or physically disqualified for education.

It might be expected that such a country would carry its professional education to a high point, and it does. Much, very much, may

be learned here of value to other countries. My many months of residence here, made necessary by illness, have not been spent in idleness when physically able to investigate the many interesting educational and social features of the country.

The schools are under the supervision of the government — federal, cantonal, and municipal. "Keeping school is the permanent business of the State," as a writer on Switzerland has well said. When a child, male or female, reaches a certain age, generally seven, the right to stay at home and play ceases; the State seizes the child and holds him fast for years and rears him into what he is to be in life.

From the great educator, Pestalozzi, the principle has been received and consistently followed that education is a developing of the faculties rather than an imparting of knowledge. "Education as the acquiring of information is one thing; it is quite another thing to develop the human forces by a thoughtfully planned course of training, mentally, physically, and normally fitting the student for complete living."

The Swiss method of teaching is never mechanical; it is gradual, natural, and rational; patient, never hurried, a slow but sure advance, and firm ground established as it goes. There are schools everywhere and of all kinds — primary, supplementary, secondary, day, evening, for the blind and the deaf, industrial, linguistic, intermediate, high gymnasium, or American college, university, polytechnic. It is a business which, when nobly done, as here, "brings bountiful return in love of order, law, right, and truth."

But these most interesting general features of Swiss educational principles and practice must give place to the special class of education we are now considering.

The high school, or gymnasium, or college, is the highest state school prior to the university or the polytechnic. About one-tenth of the graduates of the high school enter these higher professional schools; the other nine-tenths go out into life without more preparation, and it is not needed, for the gymnasium course is wisely adapted to their wants, so as to round out the education of the student, boy and girl, and graduate them with a quite complete general education.

The total time required for this education is usually about twelve years, from seven years of age to nineteen, four years in the elementary school, four in the progymnasium (the preparatory high school) and four to four and a half in the gymnasium. In the second the course of study is the same for all, but in four classes with some

variety. In the third it separates into three courses or classes, commercial, technical, and literary; graduates of the first go into business, of the second to Zürich Polytechnic, of the third to the university, into theology, law, medicine, or general literature and philosophy.

The following studies appear in the Calendar for 1897. In Class I, the last year of the progymnasium, Latin, German, French, arithmetic, algebra, geometry, natural history, geography, history, drawing, writing, and gymnastics, and nearly the same studies are pursued in the lower classes.

It will be seen from the above that the student, after those four years of study, is quite prepared to enter upon four and a half more of extended studies along the same lines. As to languages, all four of the following are taught: German, French, English, and Italian, the two former very thoroughly, since they are the languages most in use in this part of Switzerland (Canton of Bern and Zürich), and it should be noted here that in Bern the native language, spoken only, not taught, is Bernese, or, as claimed here, old German. These four languages are taught throughout the entire four years; the remaining studies are algebra, carried quite far; geometry, including analytical geometry, solid geometry, synthetic and problems; physics, acoustics, optics, magnetism and electricity; chemistry, organic and qualitative analysis; natural history, botany, with microscopic demonstrations, etc.; geography, mathematical and physical; art drawing, ancient, middle ages, and Rennaissance; geometrical drawing and practical geometry.

The last half year of the four-and-a-half-year course in the gymnasium is devoted to a careful review of all studies of the course, with some extension of each.

The Zürich Polytechnic School was first prepared for by the Swiss Republic in the Constitution of 1848, which provides for a Government University and a Polytechnic School.

The former has not been established; the latter was, by the law of February 7, 1854, placed at Zürich, and as the university was not to be established, the Polytechnic School was consequently enlarged and extended in its educational scope, so that to the original three sections of civil, mechanical, and chemical engineering there were added architecture, sylviculture and agriculture, and a course in arts and philosophy, and also a pedagogic course.

From its inception it has been the main purpose to maintain a school of superior technical instruction and training, and to give its

students, in the highest possible degree, scientific maturity for the various vocations for which they prepare themselves. It labors also to turn to the practical advantage of its students scientific theoretical researches, endeavoring always to unite in a reciprocal influence science and practice, believing that the present age has a need of highly cultivated and fully prepared technical men.

The course of study, the general and detailed methods, all conspire to accomplish this high purpose. The professors and teachers are selected with the greatest care, and among the former are men of the highest international reputation as instructors and practical scientists.

The students not only attend the lectures and work in the drawing room, but in the extensive laboratories in experiments and in original research. The great enlargements and extensions in recent years of the various laboratories show what importance the management gives to this feature of the studies. It may be mentioned here that in addition to the present buildings and laboratories referred to below, a laboratory for mechanical investigation, like the best of those in the United States, was not long ago proposed by one of the leading professors in civil engineering, Professor W. Ritter, and the proposition is now on its way towards realization.

No fixed system prevails (nor will it ever); from year to year the methods vary to suit the ever advancing state of practical science.

In the direction of tests of all kinds, and in the development of electrical facilities, unusual advances have been made recently. Through the efforts of Professor Weber, whose fame as an electrician is international, a suitable building and a very extensive electrical apparatus have, within the last year, been opened up, attracting by its remarkable character a pilgrimage of electrical experts from all parts of the world to study with the facilities and engage in original research.

As to the testing facilities, I have but to state that it is in charge of Professor Tetmajer to stamp the facilities and their use with the highest mark of perfection; so extensive and complete are they that the International Association for Testing Materials is established here under Professor Tetmajer, the president of the association.

The progress of science and of "technique," widening and extending their domain, making in consequence greater and more rigorous requirements for the preparation of technical men, have little by little forced a longer course of study in the special divisions, particularly in mechanical and electrical engineering, also in chemistry.

Including the whole seven divisions of the school, there are 167 separate and distinct courses of instruction that are obligatory, and 114 that are not obligatory, a total of 281, of which 40 have not yet been put in practice. There are regular students and attendants on lectures (*auditeurs*). This year, 1897–98, there are 858 of the former and 307 of the latter, a total of 1,165. Of the regular students, 516 are Swiss and 342 are from 20 different foreign countries, Austria-Hungary leading with 82, Germany following with 67, Italy with 33, Russia 28, Roumania 22, America (all America) 22, Great Britain 15, Holland 13, Scandinavia 12, and other countries with lesser numbers. The number of the regular students has increased from 562, in 1871, to 858 this year. The teaching staff is as follows: 60 professors, 44 honorary professors, 43 assistant teachers, assistants and private docents; total 147.

A school of this magnitude, and it may be said that the buildings and facilities are adapted to this large number of students, must exert a commanding influence on technical education and must send out to many countries competent professional engineers. It therefore deserves some detailed mention, from which a lesson may be learned for establishing similar schools elsewhere. The principle of obligatory study, obligation to conform strictly to rules, to be present at recitations and all other fixed functions, is absolute. The opposite course of freedom to students to do as they please is considered subversive of good and necessary discipline, so that the *auditeurs* must conform to all the rules and regulations and punctually attend upon the instruction. These *auditeurs* are principally found in the arts course, into which such a class of students can be admitted without fear or scruple.

The minimum limit of age is eighteen, and the applicant must have completed fully his eighteenth year. A certificate from a preparatory school of high standing and exacting requirements is accepted in lieu of an examination. The age of eighteen was decided upon in 1882, to make it more sure that the student should not be immature in his preparation.

The examination for admission is severe, and the necessity for this lies in the conviction, from long experience, that it would be extremely detrimental to the school, the students, the professors, and its development to admit students insufficiently prepared.

The examination of candidates for admission is first on general culture, and second on special subjects. In the first, orthography, style,

and logic are required in a thesis to be written in his own or any language he may select of four — German, French, Italian, or English.

He must give oral proof that he is sufficiently acquainted with the language in which the course he enters is to be taught to understand the instruction. He must submit to an oral examination in the history of literature, political history, and the natural sciences.

In the special subjects, quite extensive knowledge is required of arithmetic and algebra, of geometry to the construction and solution of problems, of stereometry, plane trigonometry and elements of spherical trigonometry, analytical geometry and conic sections, descriptive geometry quite complete, physics, elements of the theory of movement, mechanics of solid, liquid and gaseous bodies, theory of heat, knowledge of the principal phenomena and laws of magnetic and electric forces, chemistry, simple and compound bodies, atomic theory, etc., drawing, in line and figures, facility in the execution of geometrical problems and some skill in coloring, freehand drawing and some exercise in ornamental design.

Coming now to the courses of study, it would be manifestly impracticable to give more than the most general idea of them.

The school of Architecture requires three and a half years. Beginning with higher mathematics it extends to the study of styles, and includes all the knowledge required by a professional architect, such as mechanics applied to construction, art of the civil engineer, designs of ornamentation, hygiene of buildings (sanitation), modelling, and history of ancient art.

The school of Civil Engineering also requires three and a half years. Beginning with the differential calculus it extends to electrical technology, and includes, among other things, higher mathematics, architecture and civil construction, physics, topography, study of machines, industrial geology, topographical designs, graphical statics, construction of roads and railways, foundations, water works and canalization, practical geodesy, technology of constructive materials, stone and steel bridges, and study of law.

The school of Industrial Mechanics covers the same period and is fully extended, branching into more mechanical work, including the construction of machines and turbines, and other hydraulics. Electrotechnology is gone into much further, and the principles, apparatus and methods of measurement of electricity, telegraph wires and cables, and a thorough course in the electrotechnical laboratory of Professor Weber,

motors, dynamos, installation of manufactories and electric central stations.

The school of Industrial Chemistry is very complete in its course and is also three and a half years in length, going as far as the installation of various kinds of chemical works. This course requires abundance of room, and this it has in a very large building specially and intelligently designed for the purpose. There is attached to the course a section of pharmacy, requiring two years.

The Agricultural and Forestry School requires three years, and fits the young man for professional work of this kind, so important in Switzerland, where the greatest possible advantage must be taken of the rather meagre conditions to promote their highest usefulness. The course, however, gives training of use in any country. This course is thorough in agricultural chemistry and all the allied studies.

The Normal School of Mathematical and Natural Sciences carries all these and related subjects to great perfection, and turns out teachers of a high order of merit.

The Seventh Division is really a university extension course in philosophy and political economy; with it is a technical course in photography, applied topography, calculation and construction of roofs, ice machines, operation of railways, industrial hygiene, the technic of the telegraph and telephone, etc. In this division is placed military science, which is carried to great perfection in Switzerland.

The buildings are six in number. In the main building are architecture, civil engineering, mechanical engineering, normal school of mathematics and natural sciences, philosophy, political economy, and the library. Chemistry is in a large building, agriculture and sylviculture in another, physics in another, and there is a good astronomical observatory. Recently the sixth building for electro-physics has been completed, and one to be used as a laboratory for mechanical investigation above referred to will soon be commenced.

The Polytechnic is supported partly by the tuition fees and partly by the federal government, the city of Zürich, and by nearly a million francs of bequests.

I will only remark in closing this sketch, that while the laboratories are unequalled in the world and the electrical department better equipped than any other, they are used for illustration, testing, experiments, and research, and not at all for manual training in the use of tools. The old method of confining the tests to illustrations of prin-

ciples by the teachers is still employed, but in recent years the importance of testing materials has grown so rapidly that special courses have been established at Zürich in which the students are taught to execute tests themselves.

There is one important feature of this school which distinguishes it from most of the German and Austrian schools and from the general continental method. In these other countries, particularly in Germany, the students are not compelled to attend the lectures which belong to the course. They enjoy what is called "*Studienfreiheit*" (freedom of studies). There are no recitations; the students are obliged to pass through only two examinations during the entire course. The students, after their long, confining, disciplinary course in the gymnasiums and other preparatory schools, are now let loose, as it were, and they revel in the new freedom and make the most of it, often, possibly, to their detriment.

At Zürich it is entirely different. There are weekly recitations in every important course, promotions are made annually, and certificates are given the students semi-annually. Those who do not apply themselves to their studies are sent away. All this induces more earnest study and work than in the German schools.

If one takes the pains to question engineers of high standing in Austria, Hungary, and possibly Italy and other countries, he will discover that the fact of graduation at the Zürich Polytechnic is considered a sufficient guaranty of possessing the best and highest possible engineering education in all Europe. It is always with pride and confidence that the engineer answers the question as to where he was educated by saying, "I studied at Zürich," even so far away as Budapest or in Roumania.

GERMANY.

The thorough, systematic, scientific education of Germany places it high on the list of educational countries. Germany was formerly (and is still) the Mecca of those postgraduates of our country who desired to go beyond the ability of American universities and colleges and beyond their courses of study, and also beyond the professional courses of study in law, medicine, and engineering, as well as in special studies.

The engineering schools could not, in their special methods, be further improved. They were on the top and secure there, and the same may be said of purely technical and industrial education, which

has done so much for German mechanics, artisans, tradesmen, merchants, and commercial men. All these departments of industrial education are supervised and controlled by the State. The result has been that the Germans at home and abroad have commercially distanced the British, in new countries particularly, and have invaded the world's markets with their industrial output, and to such an extent have they interfered with British markets that a genuine alarm has been sounded in Great Britain, not by the educational enthusiasts alone, but by the conservative merchants and manufacturers, resulting in appeals for a higher and more thorough technical education. Secondary education is receiving just now more attention in Great Britain than ever before. Committees of investigation have been sent from Manchester and other industrial cities to Switzerland and Germany to study the methods of education, returning to their homes with unanimous reports of the superiority in every direction of the continental methods, with the prophecy that trade will be entirely lost and they will be distanced even more markedly than now if something is not done to remedy the existing unsatisfactory methods of industrial education.

We would naturally expect to find, not only the perfection of industrial education in Germany, but of professional engineering education as well, at Charlottenburg, Munich, Dresden, Hanover, Braunschweig, Darmstadt, Carlsruhe, and Stuttgart, and we do find it, especially in scientific education, as well as in experimental and research methods with the new apparatus for this work now being installed.

As characteristic of these royal technical high schools, Hanover may be taken as a fair sample of all. I have before me the *Programm* of 1897–98. Students are admitted who have graduated at the gymnasium of the first order, like that described above, at Bern. There are four departments, architecture, civil engineering, mechanical engineering, and the school of chemistry and electrotechnology and of general engineering.

The extent and thoroughness of the courses may be seen by taking that of mechanical engineering for illustration, which carries the student from his one year of practice in the shops after his graduation from the *Real Gymnasium*, through four and one-half years of instruction combined with laboratory work, from the scientific principles to the most advanced practical studies. Perhaps a better idea of the extent, thoroughness, and practicability of the course from beginning to end

may be gathered from a letter recently received from a prominent German educator, a professor in one of the best royal technical high schools.

It describes the course of education required by a mechanical engineer to enter the service of the government: from six to ten years of age in the primary schools preparing for the *Real Gymnasium;* from ten to nineteen years of age in the latter school; from nineteen to twenty in practice, one year in a workshop manufactory, though it is better to take this year of practice after a year in the military service; from twenty to twenty-five, four and a half years in the *Königliche Technische Hochschule* (Royal Technical College). At the end of two years in this college a thorough and rigid examination must be passed, and at the end of the course the final examination; success in this latter examination secures appointment as Director of Government Construction. There must then be two years of practical work in government service, and then follows an examination by the state for the final diploma.

Those who wish to enter the high service of the government as mechanical engineers must take three semesters in the university in jurisprudence and political economy.

As to laboratory methods, a remarkable change has taken place within the last few years. When I examined into this question in 1891, there was perhaps only one school (Munich) which had a steam engine for laboratory work; now all of them are fairly well equipped with a steam plant, and rapid strides are now being made in all the royal technical schools in equipping themselves with complete apparatus.

The industrial and commercial activities and ambitions, in scientific and practical directions, have given an extraordinary impulse to technical education. This has resulted in the "installation" of ample and richly equipped laboratories for engineering in connection with the engineering departments of the high schools. "All these new plants will be much larger and of wider range than ours at Munich. They are not yet finished, but in a year or two you will be astonished at seeing that we are equalling the Americans in their kind of engineering education."

"I must add, to avoid a misunderstanding, that there is no manual training at all in these laboratories; that is, we have no workshops in connection with the technical high schools, but we send the young men to practical engineering work for practical training."

The above is from a letter recently received from the director of the Munich Royal Technical High School.

I have before me descriptions and illustrations of two of these new plants, one at Darmstadt and the other at Stuttgart. They are very complete, and, being entirely new, are in accordance with the latest experience of the world. The designers have evidently personally studied all the prominent plants on both sides of the water, and have taken advantage of the good qualities and have avoided the defects of others. In the development of laboratory methods, plant and facilities, what, as in naval development, was considered suitable ten years ago is now often only fit for the scrap pile. The German technical colleges have profited by all this experience. It will soon be profitable for American technical teachers to visit these new laboratories and study their design and adopt their excellences.

As might be expected, electricity has been given a prominent place in these laboratories.

We find at Hanover all the testing machines needed for testing the strength of materials, for experiments on the flow of liquids in the face of the wind, air compressors, discharge of water through orifices, determination of contents of velocity of flow, indicators with steam, gas and petroleum engines and turbines of various kinds, with a variety of dynamos, and with many attachments for measuring electric forces.

From a letter just received from Professor Hempel, of the Dresden Royal Technical College, I learn that they have there a complete outfit of various kinds of experimental machines: three steam engines of varying power, gas, petroleum and water motors, experimental boiler, testing machines of various kinds, and an electric institute with a variety of dynamos and their attachments; and further, that this spring two new institutes will be commenced in connection with the college, each costing 800,000 marks ($200,000).

Notwithstanding the present advanced state of technical education in Germany, there is dissatisfaction and unrest and ambition for better methods, more in respect to the *personnel* than the laboratory. One of the most learned advocates of the more practical teaching is Professor A. Reidler, of Charlottenburg, who has written much earnest argument in favor of ingrafting into German methods more practicality and doing away with some of the present dogmatic teaching, which may be called a German national characteristic, which is unlike the common sense characteristics of the Anglo-Saxon peoples. He considers it necessary

to give the students "more thorough knowledge by means of practical application by teachers who understand such application and work in the spirit of true *practice* and *economy*. The teachers of the technical sciences must be acquainted with the actual facts from their personal activity, and must be masters of, and know how to put into practice, the art which they undertake to teach."

The following will apply anywhere in the world, and is in accord with the principle in full activity at the University of Chicago, where the professors and the teachers in all departments are expected to accomplish some original work and to be in earnest.

"In the technical colleges a lively *mental competition* of the teachers ought to be produced by parallel professorships and by attracting teachers from practical life. The success of the colleges and of the national productive activity is dependent upon this. The damaging of an entire generation and nation by a single college teacher who is not capable of doing his work, or whom a false or outlived reputation surrounds, is much greater than the damage which dozens of dismissed army officers would have been able to do."

If the earnest spirit and purpose and the suggestions so forcibly put become a part of German education, as they are likely to become, it can be seen that nothing but the best of schools and methods and spirit of instruction will ever be able to hold back our young men from Charlottenburg and other German centers of education.

Italy.

Any one at all familiar with Italy and its works on land and sea must come to the conclusion that these excellent constructions have behind them the best methods of engineering and architectural education. The skill of the old Romans has evidently been transmitted to their descendants. The Italian maritime engineers (I am not much acquainted with the works of other kinds) combine happily the good common sense of the British and the precision and good taste of the French. Their works are made to stand, and their proportions and designs are elegant and artistic.

I have now for the first time had an opportunity of becoming acquainted with the methods of engineering education prevailing here, through the kindness of Professor Guiseppe Colombo, member of Parliament and the director of the *Institute Technico Superiore* of Milan,

and late minister of public works; and by the assistance of Professor L. Cremona, Senator (vice-president of the Senate), and the director of the Engineering School of Application at Rome.

The programs of these excellent schools show them to be equal, in respect to the curriculum, to any of the schools of the Continent.

These are royal schools and managed by the government. There are others similar at Turin, Padua, Bologna, Naples, and Palermo.

The government engineering service, which recruits its engineers from the schools above mentioned, is very extensive and requires many engineers. The Ministry of Finance deals with all sorts of products, such as tobacco, spirits, powder, matches, salt, etc. The Public Works Department includes within its control maritime and inland navigation works. The Department of Agricultural Industry and Commerce is concerned with irrigation, the execution of laws relating to manufactories, electrical transmission, and topography. So that the government engineers require training and knowledge of various kinds, in order to be fitted for the duties of these various departments.

Employment by the government requires not only diplomas of graduation from the government schools, but in addition special examinations, which are periodically carried on at Rome, and relate to the studies particularly required in the branch of public service to which the candidate makes application for entrance.

In order that the engineering student may enter either the university (in which he must pass two years in the mathematical section before being admitted to an engineering school) or the preparatory school of the superior Technical Institute of Milan (which was founded in substitution of the two years of the university), it is necessary for him to have a diploma of the Lyceum, or of a technical institute. (The technical institutes are schools of secondary instruction, without Greek or Latin, and with special scientific courses.)

There are no limits to the age of entrance in the schools of application, but the requirements are such as to raise the age above that usually found in the entering class of American or English technical colleges. The whole course of study would be something as follows: The boy, at eight or nine years of age, enters the elementary school, which holds him for about four years; then the Gymnasium, Lyceum, or Technical Institute keeps him five to six years, the University (or the preparatory school of Milan) two years more, the School of Application three years more — total educational course fourteen to fifteen

years. He may then, if he has passed all through successfully, receive the diploma of engineer, at, say, twenty-three to twenty-four years of age.

At the Milan school there is a mechanical laboratory, with steam engines, gas engines, pumps, turbines, and other machinery for testing and experimental purposes, with a special laboratory for testing the strength of materials. The manual training method is in use at Milan for the special purpose of training the industrial section, which comprises about one-half of the students. These students are sent periodically to remain some days in several engineering workshops, so as to watch the process of casting, tool working, and the use of machinery. At the end of the yearly studies all the students make a journey together, under the direction of one of the professors, to examine the most important works of various kinds in the country, in civil engineering, railways, bridges, harbors, etc., and also some of the important manufacturing districts. Often during the semester the students are taken by the professors to workshops and factories to illustrate the studies in the various courses as they proceed with them.

There are two special electrical institutes in Italy, one in Turin and the other in the Polytechnic at Milan, the former particularly supported by local funds, and the latter an entirely private enterprise founded by the late Mr. Erbay, a great manufacturer of Milan. Both these institutes have special laboratories for conducting all manner of electrical tests, and are well supplied with dynamos and all other electrical apparatus required.

At Milan, also, in addition to this electrical course, there are three sections, civil engineering, mechanical engineering, and architecture.

The other royal schools above mentioned graduate only civil engineers and architects, and the total number graduated per annum in all the schools is about three hundred, with about fifty industrial engineers at Milan. The total number of students in all the schools is about twelve hundred.

An examination in detail of the school at Rome, in company with several of the professors of agriculture, chemistry, electricity, and civil engineering, showed this school to be well equipped in all departments. As it is purely a civil engineering school it would not be expected to have a large steam engine plant, but it has a good equipment for testing materials, and a dynamo plant with every kind of metre for measuring electrical forces and conditions.

The architectural department is not large, but gives the highest instruction under the charge of Professor Enrico Guj, one of the leading architects of Rome. He is vice-director of the school, presiding over it in the absence of Senator Cremona, who is vice-president of the Roman Senate.

Russia.

There are two polytechnic schools, at Helsingfors and at Riga, with four or five faculties, like the polytechnic schools of Germany, and their courses of study are much like those of the German schools.

There are besides these three technological institutes at St. Petersburg, Moscow and Rarkoff, with two faculties, mechanical engineers and chemistry, also two institutes for railway and bridge engineers. These are at St. Petersburg and Moscow. At St. Petersburg there is one institute for mining engineers, two institutes for architects, and also one institute for electrical engineers; this is specially to educate electrical engineers for the telegraph department of the government. Two years ago a technological institute was founded in Tomsk, Siberia. This year two polytechnic schools will be established in Kieff and Warsaw.

All the technical schools are established by the general government except the Riga School, which was founded by the municipality and the merchants. The government, however, is to give an annual subsidy to this school, and its graduates will have the same status as those of the government schools. All students must pass an annual examination successfully in order to pass from one class to a higher or to receive a diploma. Only graduates of these schools can engage in government service — on harbors, railways, telegraphs, architecture, bridges, etc.

To enter these schools the student must have graduated from a *Real Gymnasium*, as in Germany. Greek and Latin are not required; there is no limit to the age of admission. Steam engineering laboratories are just now being introduced into the technical schools. Students in mechanical engineering are obliged to work as workmen in the workshops in the vicinity, and to finish a series of bolts, screws, keys, valves, parts of machines of various kinds, etc.; also to learn to take off indicator diagrams from steam, gas, or petroleum motors.

United States.

Massachusetts Institute of Technology, Boston. This important school of technical education is so well known, both in the United States and in Europe, that there need be given only its salient features for the purpose of comparison with European schools and methods. It may be properly styled a scientific school applying its science to the useful arts. There are thirteen distinct but correlated courses of study, embracing civil, mechanical, mining, and electrical engineering, architecture, naval architecture, chemistry and chemical engineering, and courses in physics, geology, and biology, and following the last, sanitary engineering. There is also a course in "general studies" to prepare students for trade, banking, etc., requiring a knowledge of political economy and kindred studies. Admission requirements are expected to meet the case of students graduating from the ordinary American high school (not the German *Hochschule*, which is really a technical college, but like the German *Real Gymnasium*), or from the English and scientific departments of the preparatory schools for college. The examinations embrace algebra, plane geometry, advanced algebra or solid geometry, history, French or German, and English grammar and composition. The examinations are quite rigorous, and many applicants are rejected. They are expected to compel maturity. The average age of students on entering is somewhat over eighteen years, the same age as at Zürich, except that at the latter eighteen years is a requirement, and a rigid one, where if the year, for instance, begins in October and the student is eighteen in November, he cannot enter. At Boston there are some few students sixteen years of age at entrance; the ages range from sixteen to twenty-two, the average being eighteen years and eight or nine months.

The length of the regular course is four years. The aim of the course is to make the pupil observant and exact, to give him a desire and ability for research and experiment, to give him a good foundation in those studies which underlie the practice of the scientific profession, and to give him all the practical and technical knowledge required for this purpose.

There are six buildings, all within convenient distance of each other. Everything is on a large scale, and it must be to take care efficiently of about twelve hundred students, the number taught in 1896–97. There were, in the same year, 153 teachers, including professors, associate

professors, assistant professors, instructors, assistants, and lecturers. The students come from thirty-nine States of the United States; the larger number, or about sixty-one per cent., were from Massachusetts; twenty were from foreign countries. Since 1890 twenty-nine foreign countries have had representatives in the lists of students.

There were last year eighty graduate students[1] engaged on special studies; sixty-nine of these are from other institutions, some of them being the foremost colleges of the country. Women are admitted to many of the courses; there were seventy-one in 1896–97.

The degree of Bachelor of Science (S.B.) is given for the successful completion of any of the four-year courses, followed by advanced degrees upon completing advanced courses at the Institute.

To go into the details of the equipment of the buildings would be impracticable. All of them for their various purposes are completely equipped with everything required for teaching, illustrating and experimenting, and for research work. While there are extensive workshops they are not considered "factories" but laboratories. "It is not the thing made, but the training, the discipline, the practice, which the student obtains in the making."

A brief summary of the equipment must certainly be given, otherwise no adequate idea of the scope and extent of the school could be formed. In the woodworking department are forty carpenter's benches, two circular saw benches, a swing saw, two jig saws, a buzz planer, a mortising machine, thirty-six wood lathes, a large pattern maker's lathe and thirty-six pattern maker's benches. The foundry contains a cupola furnace, two brass furnaces, a core oven and thirty-two moulder's benches. The forge shop contains thirty-two forges, seven blacksmith's vises, and one blacksmith's hand drill. The machine shop contains twenty-three engine lathes, seventeen hand lathes fitted with slide rests, two machine drills, three planers, a shaping machine, two universal milling machines furnished with spiral and gear-cutting attachments, a universal grinding machine, a cutter and ream grinder, a 24-inch standard measuring machine, thirty-two vise benches arranged for instruction in bench work, and a fully equipped tool room. A power hammer will be added to the equipment of the forge shop during this year. It will be noted that this equipment is not in the laboratories or for laboratory work.

[1] The number during the year 1902–03 is 161, out of a total of 1,608 students.

There are practically eight distinct laboratories: for physics, chemistry, mining and metallurgy, engineering (including applied mechanics and hydraulics), biology, architecture, and geology, and the mechanical laboratory, or workshop, above mentioned.

There are eighteen separate rooms in the laboratory of physics alone, many of them of large size, devoted to general physics, electric dynamos, electric engineering, heat measurements, physical chemistry, acoustics, and optics. The laboratories comprise in all thirty rooms. The engineering laboratory is very complete and extensive, occupying two floors in the large engineering building; it comprises steam engineering, hydraulics, testing, and a room for cotton machinery.

The steam department has a triple expansion engine of 160 H. P., with smaller steam engines. The hydraulic laboratory contains a closed tank 5 feet in diameter and 27 feet high, connected with a standpipe 10 inches in diameter and 70 feet high; all necessary connections are made with it for every variety of hydraulic experiments, and one finds all sorts of hydraulic metres, pipes, gauges, weirs, various orifices, nozzles, etc.

The laboratory for testing materials has, first, an Emery testing machine of 300,000 pounds capacity, also one of 100,000 pounds, for testing transversely.

The biological laboratory is unique and important; it is used mainly for the purpose of the investigation of the physical, chemical, and physiological conditions of sanitary problems in water supply engineering.

In the architectural laboratory are not only all the modelling apparatus required, but a complete plumbing system for study.

The geological laboratory provides for mineralogy, lithology, and structural and economic geology. These various departments and laboratories have conveniently at hand their own departmental libraries, some of them quite extensive and all well selected. There is also a large general library. All books and all instruction in the laboratories have for the main purpose the teaching of scientific and practical engineering. The total number of volumes and pamphlets in all libraries is about 55,000.[1]

It may again be remarked here that it is the purpose always to make *professional* engineers, not mechanics. All work in laboratories

[1] The present number is about 80,000. — ED.

and shops is considered as so many problems, teaching various operations and the use of the appropriate tools, the work being considered necessary from the point of view of mental as well as manual training.

To give the various courses of study covering all departments would be impracticable, but in order to convey an idea of them one will be given, that of electrical engineering, the five years' course, which comprises the same studies carried to the same extent as the regular four years' course, it being instituted to permit students to take a year's extra time for the course.

VI. Electrical Engineering.

FIRST YEAR.

First Term.	*Second Term.*
Algebra (or Solid Geometry)	Analytical Geometry
Plane Trigonometry	Plane Trigonometry
Rhetoric and English Composition	Political History since 1815
French or German	French or German
Mechanical Drawing	Mechanical Drawing and Descriptive Geometry
Freehand Drawing	Freehand Drawing
Military Science	Military Science

SECOND YEAR.

First Term.	*Second Term.*
General Chemistry	General Chemistry
Chemical Laboratory	Chemical Laboratory
Carpentry and Metal Turning	Carpentry and Wood Turning
Differential Calculus	Integral Calculus
Descriptive Geometry	English Literature and Composition
English Literature	German (or French)
German (or French)	
American History	

THIRD YEAR.

First Term.	*Second Term.*
Acoustics	Physics
Physics, Mechanics, Wave Motion	Physical Laboratory: General Physical Measurements
Electricity	Magnetism, Electricity
Principles of Mechanism	Mechanism, Gear Teeth
German (or French)	Machine Tools
Political Economy	Drawing
Business Law	German (or French)
	Political Economy and Industrial History
	Business Law

FOURTH YEAR.

First Term.	*Second Term.*
Physics: Heat	Physical Laboratory: Heat and Electrical Measurements
Physical Laboratory: General Physical Measurements	Theoretical Electricity
Theoretical Electricity	Electrical Measuring Instruments
Methods of Telegraphy	Steam Engineering, Boilers
Steam Engineering: Valve Gears, Thermodynamics	Engineering Laboratory
Drawing	Drawing
General Statics	Strength of Materials: Kinematics and Dynamics
Method of Least Squares	Precision of Measurements

FIFTH YEAR.

First Term.	*Second Term.*
Technical Applications of Electricity	Technical Applications of Electricity
Physical Laboratory: General Electrical Testing	Engineering Laboratory
Theory of Alternating Currents	Differential Equations
Photometry	Thesis
Steam Engineering	*Options*
Dynamics of Machines	Physical Laboratory
Hydraulics	Mathematical Theory of Electricity
Engineering Laboratory	
Strength of Materials: Friction	

Worcester Polytechnic Institute, Worcester, Mass. No doubt this excellent school, presided over by Dr. T. C. Mendenhall, of international reputation as a leading practical scientist, takes front rank with the best schools of the world.

The requirements for admission are a minimum age of sixteen years; average age is actually over eighteen.

Examinations must be passed successfully in United States history, English language, algebra, plane and solid geometry, French or German. In reference to the English, the requirements, beginning in 1899, are those adopted by the New England Association of Colleges and Preparatory Schools. All the subjects above mentioned must be fully understood. A suggestion is given in the requirements that it would be advisable, before applying for admission, to take a full high school course, "including, if possible, such knowledge of Latin and Greek and ancient and mediæval history as is generally required for admission to college."

At the date of founding the institution, 1865, and in the generation preceding, any one desiring to enter a branch of the engineering

profession had to serve for a longer or shorter period with some expert practicing engineer as an apprentice, and pick up what professional knowledge he could, under often very unfavorable conditions. If he began this apprenticeship in early life he was forever held back from a high and useful position by the lack of a liberal education. If he obtained the latter before he entered upon his engineering work he had still to begin at the bottom to learn the rudiments of engineering.

The object of founding the Institute was to combine in the school two essential conditions of success — study and laboratory work. As to the laboratory, a distinction is made between machinery and manual training. The dominant idea is that the former is essential, and in these days of machinery development the latter is not, except for the mechanic and artisan, which the school does not pretend to send out.

"In the so-called manual training schools, or in trade schools, this other is, and sometimes must be, the end in view; but in the education of the engineer exercises in the workshop should be planned and conducted so as to furnish a discipline and a training of a distinctly higher order."

In the very extensive workshops this end is always kept in view, and the greater part of the output of the shops "consists of special machines, appliances and devices which have been originally designed and developed there, and which represent the result of actual engineering practice on the part of the students and professors." These extracts are from the Calendar of 1897–98.

There are five courses of study: mechanical, civil, and electrical engineering, chemistry, and a general scientific course. They are each four years in length, with an opportunity for an advanced year's work in electrical engineering.

The plan of instruction is by lectures, recitations, and laboratory and workshop practice. The scope and extent of each course is fully as great as that of the Massachusetts Institute of Technology previously mentioned. The laboratories are equipped with the latest and best machines and other appliances for all manner of experimental work and tests.

Engineering as a Learned Profession.

We have now taken all the space and time at command in outlining the methods of education in many countries. The national differences

appear plainly, and need not even be summarized; it might lead to invidious comparisons to do so, and consequently to criticism and misunderstanding. I must leave you to form from the description your own conclusions as to which country or countries possess the best methods. What is best for one may not be for another; "circumstances alter cases" in nothing more than in educational methods. What might be necessary for a young man to have in the way of training in Worcester, Massachusetts, might not be at all suitable for a young man in Worcestershire, England, or in Bern, Switzerland. What I wish to present ultimately is the character of the school that ought to be founded in connection with the University of Chicago. I must, however, call attention to some developments of the general subject and to some features of the development of engineering itself as a learned and important profession.

Referring first to Great Britain, the birthplace, almost, of modern engineering, it may well be said that the subject of engineering education has there received great attention in the way of investigation, at least, by the Institute of Civil Engineers, in London, the largest and confessedly the most important and highest institution of the kind in the world.

As long ago as 1870 the subject was fully inquired into by the council, again in 1891, and successive presidents of the institution have considered the subject important enough to give much space to it in their inaugural and other addresses. More important still are the recent orders of the council to require a scientific and practical training and knowledge on the part of student and associate members, to be attested by examinations conducted by the council, or by diplomas and degrees from specially designated schools and universities.

We may, therefore, at the outset conclude that the "rule of thumb" engineer will have no opportunity to show his ignorance in the future. In fact, it may be stated broadly that the civil engineer of the twentieth century must be an educated man, and specially prepared for his life work by the highest order of educational instruction and training.

But it has not always been so; steam and electricity, the potent forces of the present time, have been developed in little more than half a century. They, more than any other causes, have produced the civil engineer and raised him to rank with the older "learned" professions. He starts with the twentieth century on the same high level with them, and it is the circumstance of this situation that calls for that sort of education that will best meet this condition of affairs.

It is instructive and interesting to read the literature of the last thirty years as it appears in the proceedings of the Institute of Civil Engineers, and it is amusing, almost astonishing, to read in extracts from a lecture on "The Education of Civil and Mechanical Engineers" in 1868, by Professor Fleeming Jenkin, delivered in the University of Edinburgh, the description of the attainments of young engineering "apprentices" and "pupils" in workshops and engineers' offices:

> Young men, at the age of about eighteen, enter the office of a civil engineer. Usually few questions are asked as to previous training. Etiquette requires the engineer to show a certain reluctance to receive the pupil, and, in fact, the ordinary pupil is a sort of nuisance in an office, only tolerated in consideration of the fee which accompanies him. From personal experience I can declare that most pupils are so ignorant of algebra that they are not only incapable of working out a result for themselves, but actually cannot apply the simple formulæ which are given in engineers' pocket books. The calculation of the solid contents of a wall is often beyond their powers. Their arithmetic is very shaky, and a knowledge of physics, chemistry, geology, or the higher mathematics is wonderfully rare.

Speaking generally of the British system of engineering education of that time, he said, "Our defect is the want of a good knowledge of the theories affecting our practice."

The well-known and distinguished scientific engineer, the late John Scott Russell, F.R.S., in 1869 expressed forcibly and clearly the defects at that time existing, in a lengthy *brochure* on the subject of "Systematic Technical Education for the English People." Comparing English and continental methods of actual works, he says:

> I will now come to the practical matters which show directly the results of a technical education in the production of one of its chief objects — the creation of wealth. It is notorious that most foreign railways, which have been made by themselves in the educated countries of Germany and Switzerland, have been made far cheaper than those constructed by us in England; it is known that they have been made by pupils of the industrial schools and technical colleges of these countries, and I know many of their distinguished men who take pride in saying that they owe their positions entirely to their technical schools. I find everywhere throughout their work marks of that method, order, symmetry, and absence of waste which arise from plans well thought out, the judicious application of principles, conscientious parsimony, and a high feeling of professional responsibility. In the accurate cutting of their slopes and embankments, in the careful design and thoughtful execution of their beautiful but economical stone masonry, in the self-denying economy of their large span bridges, the experienced traveller can read as he travels the work of a superiorly educated class of men; and when we come down to details, to the construction of permanent way, arrangement of signals, points and sidings, and the endless details of stations, we everywhere feel that we are in the hands of men who have spared no pains, and who have applied high professional skill to minute details.

Introducing the subject of "What Technical Education Should Be Given the Civil Engineer," he again alludes to continental methods, and pays a deserved tribute to the thorough education in France, which I have described above:

> The great public works of a civilized country have always demanded and generally received from its government earnest solicitude and forethought. In France, the civil engineers are the *élite* of the nation; the most distinguished pupils throughout the country are promoted into the central technical institution of France in Paris; and out of this again a selection is made of the most talented for the *corps de génie maritime;* for the *corps de génie militaire;* and for the *corps de génie civil*, or *ponts et chaussées.*
>
> By the great public works of a country so much is gained or lost to the public well-being, that the most liberal measures are justified if they succeed in providing for its service the profoundest knowledge, the most brilliant talent, and the highest skill.

Nine years later, 1878, speaking in his presidential address upon what great things have been accomplished in the world by the civil engineer, Mr. J. F. Bateman said:

> Still, there can be little doubt, on a review of the whole question, that our young engineers are not always prepared by preliminary education as well as they might be for their subsequent acquisition of practical knowledge. It is not because there are not institutions in this country where this knowledge can be obtained, but rather from a general laxity in the views of parents and guardians upon technical education. Special qualifications, and some of a very high order, are required to insure success in our profession, and many young men enter it as pupils without these qualifications.

Coming now to the present time, I cannot forbear the quotation here of a few brief extracts from the inaugural address, on November 3, 1898, of Sir John Wolfe Barry, president of the Institution of Civil Engineers. The whole address is worthy of the most careful reading, because, being a "jubilee" year, the president felt called upon to show what the engineering profession had accomplished in the sixty years of Queen Victoria's reign. The reading of that address would set at rest all doubts, should there be any, as to the necessity of giving civil engineers the highest and widest education possible.

I can only give here a few extracts from this admirable address, those which relate to the special subject in hand. He had just been exploding the idea that ours is the culminating epoch of the world's history by giving the increase of the world's population and the room yet for it, and remarked that we might realize the absurdity of calling

ours the culmination when we reflect that the present population of the world could stand upon the Isle of Wight:

> All these matters are of supreme interest to engineers, and reflect a strong light upon the present and future importance of our profession, which has, as I have said, advanced in so marked a manner in members, consideration, and position in the last sixty years. Without for one moment decrying the status of the able engineers who exercised their craft prior to 1837, I think it may be said that the queen's reign has, practically speaking, witnessed the birth of engineering as a profession of a most important character, and bearing, perhaps, more responsibility in respect of life and expenditure than is supported by any other calling.
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> I have enlarged upon the subject of the exploits and triumph of the engineering profession, not in a spirit of boasting, as the representative, for the time being, of a profession to which I am proud to belong, but with a view of pointing out the dignity of our calling, and the burden laid upon us thereby, as members of this great institution, of not letting that dignity suffer any loss or disparagement in years to come.
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> No profession requires more education, theoretical and practical, and more training of the mind than the profession of a civil engineer.
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> I must content myself by saying that in France, Germany, Austria, Russia, Belgium, and Holland, the greatest attention is paid by the State to a strict scientific training, and that the utmost care is taken to see that all candidates for employment as civil engineers are, so far as technical education is concerned, thoroughly equipped for the work which may lie before them.

With the following opinions I am in full accord, and I give the remarks upon the subject in full, as they might well introduce my own recommendations to follow at the close of this report. Sir John had been speaking of the requirements and examinations for admission to membership in the Institution of Civil Engineers:

> Again, as for students so for associate members, I myself am of opinion that we ought not to be content, in the case of the more advanced grade, with any low standard of general education. Of late years I rejoice that we have required examination in general education, as distinguished from scientific attainments, from intending students of the institution, and I think we may now all congratulate ourselves that this step, as to which there was some doubt, was taken. It tends distinctly to place our calling in its proper position among professions, and I hope some day to see that any intending associate member who has not entered as a student should be proved to possess at least those elements of a liberal education which we require from students, as well as technical and practical knowledge of his business. For I hold that education and instruction are not convertible terms, and that education implies that general exercise of the mind which brings out the best qualities of the human understanding and enables it to acquire and assimilate special instruction. It is somewhat like that training of the bodily powers which we call

athletics and gymnastics, fitting a man for the particular physical requirements which may in the future be laid upon him.

The education preliminary to the purely technical, which in my opinion, and I may add in the opinion of many of our best engineering educators and engineers, is necessary in these days, and which is at least suggested in the opinion of Sir John Wolfe Barry, above expressed, is more fully outlined by one of the most accomplished engineers and educators in the United States, Professor William H. Burr, professor of civil engineering in the Columbia School of Mines, New York City, who is not only experienced as an educator, but as a practical engineer.

I quote the following extracts from a paper on "The Ideal Engineering Education," read before Division E of the International Engineering Congress, held at Chicago, 1893:

> In the older learned professions this sequence of broad and general cultivation prior to, and forming the foundation of, the subsequent professional training is well defined, and the ultimate nature of the case in engineering is precisely the same as that in law or medicine. By means of a liberal training the requisite powers of observation and a sound judgment are more symmetrically developed and far more accurately applied in consequence of truer conceptions of the object on which they are brought to bear, and a correspondingly enhanced power of healthy mental assimilation is acquired. The broad cultivation, it matters little when or where it is obtained, is the only effectual corrective for that narrow and malformed excellence in some special direction, which, while it is certainly better than no excellence at all, falls lamentably short of the vigorous and well-rounded product of the ideal education in engineering. The writer unhesitatingly places, therefore, as the first and fundamental requisite in the ideal education of young engineers, a broad, liberal education in philosophy and arts, precedent to the purely professional training.
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> The complete and satisfactory discharge of such functions cannot, from their very nature, be accomplished on a bare possession of technical knowledge. This is indeed essential, but it is just as essential, and perhaps more so, to know how to use it.
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> There are, then, few professional men to whom the broadly cultivating influences of a liberal education are more needful than to the engineer. His early professional practice does not induce any development which can fill the voids of a faulty general education, while his latter practice demands what only liberal training can supply.

These views were advanced in 1893. I was desirous, for the purposes of this report, to know if the experience of the last four years had confirmed or changed these broad views of engineering education,

and I wrote to Professor Burr accordingly. While the reply is in a personal letter, I hope he will not object to my quoting directly from it, and I do so mainly for the purpose of expressing through him my own views from long study, experience, and close observation. His letter is dated February 11, 1898:

> My ideas as to engineering education have been nurtured more in active practice than in the class room. The cumulative results of observation seem to me to show with demonstrative force that the broadly educated engineer is in general the engineer who reaches the highest degree of success in the profession. He certainly has the best balanced and the most comprehensive view of large engineering problems, enabling him to reach the best results in the best way. It goes without saying that most of the successful engineers of the present day have not had a liberal education, although I believe they would have succeeded to a greater degree had they enjoyed that kind of a training. The real question now, however, is, what will the present engineer need? I believe that he, like the lawyer and the physician, already needs the broad, liberal education on which to base the technical training. His liberal education may well be trended toward that which is to follow, but it must be broad and liberal.
>
> Chiefly through my efforts, I am glad to say, Columbia has provided for the main features outlined in my paper. In the college course (four years) a student may now take civil engineering options, which shall be counted for the B.A. degree, so that at the end of his four-year college course (having taken B.A.) he can enter at the beginning of the third year in the regular civil engineering course, and two years later take the degree of C.E. This makes a six years' course in civil engineering now established, and a number of students are taking it. I am confident that we shall get excellent results from it. In our regular fourth year class of civil engineering, eighteen in number, we have three college graduates, one being from Harvard. These facts, in our own experience, seem to me to indicate clearly the kind of department now needed in engineering education. Details may, and probably will, need amplification, but the ground principles are right.

My own views on this feature of the subject I presented to the annual meeting of the Society for the Promotion of Engineering Education at Springfield, Massachusetts, in 1895, in a paper entitled, "The Civil Engineer of the Twentieth Century." In it were corroborating views of not only Professor Burr's opinions, as above quoted, but those of other men of prominence, not only engineers but of other professions. These views all accorded with those of Professor Burr as expressed above.

I may add that the observation, examination, conferences, and correspondence during the last two years, and especially during the last ten months, while engaged upon investigations in Europe, have strengthened me in my views then pronounced, and I lay it down here as a "*sine qua non*" that the engineer should be liberally and broadly educated, not

only in the technique of his work, but in the arts, the "humanities"; not necessarily in an extended linguistic course, though I believe that a fundamental knowledge of Latin and Greek and the literary discipline that the training in those languages gives are of inestimable value. Certainly a thorough knowledge of French and German and English is absolutely necessary.

You have followed my description of European education and the concurrent views of some of the engineers; you must hold with me that the thorough, liberal education of the Continent is the best to produce the highest order of professional men. I am satisfied that, if any one will examine the methods of work in all branches of engineering on the Continent, the enconiums bestowed upon them by Mr. John Scott Russell three decades ago, quoted above, remain true today. My observations, and they have been in the shape of investigations of European harbor constructions, terminal facilities, dredging appliances and methods, river rectifications, railway constructions, and canals, all show the effects of thorough education and an intelligent application of scientific principles.

I am glad to state that the tendency in the United States is constantly now towards a higher and broader education for professional engineers; mind, I am not anywhere discussing the education of mechanics or foremen, or of the ordinary helper on engineering work, but that required by professional men.

I have before me an address delivered in 1896 by Professor Mansfield Merriman, of Lehigh University, as president of the Society for the Promotion of Engineering Education.

He speaks always along those lines that tend upward, and few men have had more experience, or are more observing and studious, or have higher ideals.

It is a satisfaction to know from him that "in every university it is found that the activity and earnestness of the engineering students is a source of constant stimulus to those of other departments. Thus scientific and engineering education has tended to elevate the standard and improve the methods of all educational work."

The following, referring to a forthcoming report at the meeting where he delivered his address, will confirm the decided views of the Zürich faculty in regard to age of admission and a stringent demand for thorough and broad preliminary training:

> The report of the committee on requirements for admission, which will be presented later in the session, sets forth many facts which show the tendencies now existing. Almost without exception a higher standard is demanded, both that students may enter with better mental training, and that more time may be available in the course for technical subjects. While the general line of advance is towards an increase in mathematics and in modern languages, there is also found, particularly in the central States, a demand for broader training in science.
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> The general increase in requirements for admission tends to raise the average age of the student. It is now usually the case, owing to the greater length of time needed in preparatory work, that the average age of the classical student is one year higher than that of the engineering student, or the former has had one more year of training than the latter. One more year of training means much as an element for success; one more year in age means an increase in judgment which is of the highest importance for a proper appreciation of the work of the course. The older men in the class usually do the best, if not the most brilliant, work, and after graduation their progress is the most satisfactory. It thus appears that all tendencies that raise the age of entrance are most important ones and deserve hearty encouragement.

My own views stated above could not be more clearly or more forcibly expressed than by President Merriman in his concluding paragraph, which is so important that I quote it entire:

> Looking now forward into the future, it is seen that in our efforts for the promotion of engineering education a wide field for work still lies open. The student should enter the engineering college with a broader training and a more mature judgment. The present methods of instruction are to be rendered more thorough and more scientific. In particular, the fundamental subjects of mathematics, physics, and mechanics are to be given a wider scope, while the languages and humanities are to be so taught as to furnish that broad, general culture needed by every educated man. In general, let it be kept in mind that education is more important than engineering; for the number of men who can follow the active practice of the profession will always be limited. Hence let it be the object of engineering education to influence the world in those elements of character that the true engineer possesses, so that every graduate may enter upon the duties of life with a spirit of zeal and integrity, with a firm reliance upon scientific laws and methods, and with a courage to do his work so as best to conduce to the highest welfare of his country and of mankind.

I do not wish to trench upon the general subject of education, but it is difficult to separate engineering education from education in general, for the former will in no country ever attain its perfection until national and general methods are in full accord.

It may be the opinion in the United States and Great Britain that continental methods remain as they were many years ago; that "dead languages" and "pure theory" and "abstract science" have not per-

mitted the inroads of modern thought and discovery. Nothing could be further from the truth.

It is scarcely more than a year since the University of Paris was reëstablished in a city where subversion by modern ideas would not be thought practicable, especially as this university was simply securing a restoration to its honored place, held long before Oxford and Cambridge came into being. It was the "Mother of Universities," but was wiped out of existence in 1808 by Napoleon I. What is it to be now, this most ancient seat of learning, inaugurated by the most enlightened men of the most enlightened city? The president of the council pronounced it a practical university; no chair is to be without its laboratories; the entire establishment is to be one immense factory, adapting all branches of learning to the present great diversity of scientific truth and work.

The ideas advanced on that memorable occasion all tended distinctly, not only to specialization, but first to a thorough preparation for it by a university education.

President Gilman, of Johns Hopkins University, in a review of this inauguration, stated that, while American education is still far behindhand, there are distinct evidences "that during the next half century changes just as remarkable and just as beneficial will occur in the organization and administration of schools of every grade as those which have occurred in the last forty years, in which schools of investigation have been created with universities, colleges have introduced laboratory methods, technological institutes have been established in large cities, but all brought about without diminishing the respect that is paid to literature and history."

As to the German methods of general and special education, all will acknowledge that they are active, enthusiastic, thorough and deep, instinct with life and originality. It is these characteristics that have sent our young men to Germany ever since the close of our civil war. These methods have largely been copied — at least the inspiration came from Germany largely — by the multitude of our own people who came back enthused with the German way of teaching.

It was a revelation to those pioneers to Berlin and Heidelberg and Göttingen to find there such entirely different methods of education than existed in England and the United States, where instead of the dull routine of musty text-books, with the recitations from them presided over by the dull professor, living lectures, original research,

enthusiastic teachers with high ideals and souls earnest in creative effort and scientific discovery led the student on in earnest work. Is it a wonder that our ideas became Germanized? You will see from my brief statement of the present methods of engineering education in Germany that there has been, on these lines at least, no retrograde movement; they still lead, and the whole world knows it.

This earnestness and progressiveness pervades all branches of education, not only among the higher, but the middle and lower classes. As I have already shown, it has made its effect felt in the entire industrial world: first, of Germany, and second, wherever Germans go, and that is everywhere in the world.

We have not, unfortunately — perhaps some will say fortunately — state supervision of our education, either liberal or scientific; we have consequently wasted effort, and have come towards correct methods of education slowly, haltingly, and in a desultory and spasmodic manner. There has been division of forces and differences of opinion, and not concentrated, persistent, logical, and consistent educational methods like those of continental countries which, so far as engineering education is concerned, I have described. The following important truth was not patent to us for a long time, as expressed by a prominent educator, who said that the faults of education existing with us "might have been avoided had the people sooner realized that the quality of education in the whole state is determined by the quality of that at the top, and that the *State is responsible for its excellence.*"

Recommendations.

Though handicapped by our democratic conditions, which leaves the State out of the question and compels us by individual effort and by the munificence of individuals to accomplish what great nations undertake to do on this (European) side of the water, we ought with such an institution as the University of Chicago, founded, as it is, on correct principles and endowed with means (limited somewhat, it is true) to carry them out in practice, we ought, I say, to make no mistake; and we should learn from what is done best in the world and from how it is done to establish that kind of engineering school that will meet the wants of the higher educational aspirations of those young men in the United States who demand the best there is of educational methods

and facilities, and who will certainly go to Switzerland or Germany or France to find them if we do not ourselves furnish them.

The proper name of the school which ought to be established with the University of Chicago is the "University College of Engineering and Architecture." The fact that it is to be an integral part of the university is an immense advantage at the outset, for I think it is generally conceded that wherever such schools are connected with universities there is, other things being equal, an economy in teaching power and a tendency towards greater breadth of culture by the student mingling with those whose work lies in other fields of knowledge than his own. Another important advantage is the fact that there are already established such excellent laboratories of physics and chemistry. It should not be a part of the scheme to train foremen and mechanics; these can obtain their education and training in the manual training schools and the polytechnics, like that recently established at Peoria.

The college should be equipped, however, with practically the same laboratory facilities as those at Boston, Worcester, Sibley College at Ithaca, Zürich, and the new establishments in the German Royal Technical Colleges, or like that of the Central Technical College, London; that is, all that is necessary to teach professional engineers in civil, mechanical, electrical and mining engineering, and architecture.

I cannot go into the details of this plant, but will refer you to a paper entitled, "The Equipment of Engineering Schools," read before Division E of the International Engineering Congress in Chicago, 1893, by Professor R. E. Thurston, director of Sibley College, Cornell University. This paper gives in a few pages, in the clearest possible manner, the general requirements, particularly in respect to mechanical engineering.

I am in full accord with the entire paper; it is by an expert, so acknowledged all over the world, and his judgment cannot be for a moment questioned. He starts out with the statement that the profession of modern engineering exacts from its members "a more extended preparation, a more arduous professional course, than are commanded today by the schools of either law or medicine, and this fact, if there were no other corroboration of the conclusion, has fully established the engineer in his position as a member of a profession and of a learned profession." He then outlines the nature of the equipment, its exact adaptation for the purpose, and the general character of that required for experimental engineering.

His view is that the application of scientific methods to the solution of engineering problems promises to do more for the world than has any other systematic professional work ever yet undertaken.

This statement, and his concluding remark, I heartily endorse: "Upon the thorough education of our engineers depends very largely the future progress of the nation."

The admission requirements should be of the most advanced kind, with the intention of limiting the college to graduates of the academic colleges, or to students with equivalent training, as understood in the calendar of the university. In other words, it should be an advanced course of education, the students coming to it with such a preparation in arts and science as a degree from any good college of high standing would presuppose.

I am not expected, and do not intend, in this general report to go into details; my purpose has been mainly to exhibit, as fully as possible, the methods actually employed in various countries, from which to form an opinion as to the necessity of an engineering college and its general aims and features, its scope and methods.

You will naturally ask, after surveying the situation, as to what we already have and what we need to supply, what will be the cost of endowing such a college? I have had before me for study some information as to costs elsewhere, but not enough to go into details here; and the estimate which I made some years ago, though I think I have never stated it before, is not less than $2,000,000 for the building, or buildings, the equipment of the laboratories, the general teaching facilities, a good technical library, and to supply from the interest on the remainder of the sum the deficiency between income and expenditures.

The man, or men, who would undertake to thus endow such a college would be benefactors of the human race, and their influence would extend through such an institution to the remotest bounds of civilization, and to the United States, to its industry and commerce, the benefaction would be of inestimable value.

Rome, Italy, March 5, 1898.

Supplemental.

Since the above was written, five years have elapsed — a semi-decade of important development, educationally and otherwise, in this and other countries.

During this time I have had exceptional opportunities in this country, in Europe, and in South America, to observe and study, and my opinion is confirmed by this experience that the necessity for such a college of engineering as I have recommended is greater now than five years ago, and that it is the duty and the high privilege of the University of Chicago to establish this school.

In only one particular would I modify my views. I would double my estimate in order that the school may have all the facilities required and be unhampered in its development and usefulness; and while I would provide for the admission of students who cannot obtain a liberal education in the humanities, I would never lose sight of the main purpose of the college, which is to give a university, or professional, education.

1 Nassau Street, New York, June 5, 1903.

CONTRIBUTION FROM THE DEPARTMENT OF FOOD AND DRUG INSPECTION OF THE MASSACHUSETTS STATE BOARD OF HEALTH.

READINGS ON THE ZEISS BUTYRO-REFRACTOMETER OF EDIBLE OILS AND FATS.

BY HERMANN C. LYTHGOE.

THE Zeiss Butyro-Refractometer has been in use for a number of years for the purpose of determining the purity of butter, and it is gradually being used for other oils and fats. As the refractions of oils and fats vary with the temperature, a table giving the readings for different temperatures greatly enhances the value of the instrument.

Four such tables have been prepared and published, namely, one on butter, published by Zeiss to accompany the instrument, and one on lard by Hefelmann[1] and two by A. E. Leach,[2] on olive and cottonseed oils, respectively.

The writer has calculated tables for several other oils and fats and has incorporated them with the above mentioned tables into one table, arranging the oils and fats in the order of their refraction.

The oils of known purity used in the work were obtained from the following sources:

Expressed in the laboratory: peanut, sunflower, and lard oils, lard stearine, and mutton tallow.

Larned and Bird Oil Works, Brighton, Mass.: beef tallow, beef oleo, and beef stearine.

United States Department of Agriculture: peanut, poppyseed, rapeseed, mustard, and corn oils.

A. Colburn & Co., Philadelphia, Pa.: mustard oils.

Dr. Gill, Mass. Institute of Technology: corn oil.

Winthrop Chocolate Co.: cacao butter.

The other oils were commercial oils of undoubted purity.

[1] Pharm. Centralhalle, 1894, p. 497.

[2] Thirty-first annual report of the Mass. State Board of Health, 1899, p. 647.

The following table gives the actual readings obtained by the writer, together with the difference in reading for a variation of 1°C. in temperature, and the calculated reading at 35° C.

TABLE I.— ORIGINAL DATA.

	Scale Reading at 35°.	Difference in Reading for 1° C.	Temp. Cent.	Scale Reading.	Temp. Cent.	Scale Reading.	Temp. Cent.	Scale Reading.
Cocoanut Oil,	37.0	0.51	19.0	45.1	39.0	40.0	45.5	31.4
Beef Stearine,	47.0	0.525	. .	. .	44.0	42.4	56.0	36.1
Beef Stearine,	47.4	0.525	. .	. .	44.0	42.8	56.0	36.5
Cacao Butter,	49.1	0.541	35.0	49.1	43.5	44.5	54.5	38.9
Beef Tallow,	49.1	0.50	35.0	49.1	43.8	44.8	. .	. .
Mutton Tallow,	49.1	0.50	40.5	46.3	47.5	42.3	67.0	32.6
Lard Stearine,	50.2	0.526	35.0	50.2	62.0	36.0	. .	. .
Beef Oleo,	50.6	0.588	25.0	55.9	35.0	50.6	. .	. .
Beef Oleo,	50.7	0.588	25.0	55.9	35.0	50.7	. .	. .
Lard Oil,	54.2	0.526	16.0	64.2	28.0	58.1	35.0	54.2
Peanut Oil,	59.5	0.567	25.0	64.9	31.0	60.5	49.0	51.5
Peanut Oil,	59.8	0.547	18.0	69.1	25.5	64.6	35.0	59.8
Rapeseed Oil,	62.1	0.577	18.0	71.9	25.5	67.5	35.0	62.1
Rapeseed Oil,	62.2	. .	35.0	62.2	. .	. .	. .	. .
Yellow Mustard,	62.3	0.58	18.0	72.1	25.5	67.8	35.0	62.3
Yellow Mustard,	63.2	0.555	19.0	72.1	29.0	66.5	46.0	57.1
Black Mustard,	65.4	0.57	19.0	73.3	29.0	68.8	46.0	57.9
Black Mustard,	64.0	. .	35.0	64.0	. .	. .	. .	. .
Sunflower Oil,	64.5	0.59	14.0	76.8	35.0	64.5	65.0	47.8
Corn Oil,	65.0	. .	35.0	65.0	. .	. .	. .	. .
Corn Oil,	65.1	0.58	18.0	75.0	25.5	70.6	35.0	65.1
Corn Oil,	65.2	. .	35.0	65.2	. .	. .	. .	. .
Poppyseed Oil,	65.5	0.577	18.0	75.3	25.5	70.6	35.0	65.5

TABLE II.—CALCULATED READINGS ON BUTYRO-REFRACTOMETER.

TEMP. C.	COCOA-NUT OIL.	BUTTER.[1]	BEEF STEARINE.	CACAO BUTTER.	BEEF TALLOW.	LARD STEARINE.	BEEF OLEO.	LARD.[2]	LARD OIL.
45.0	31.6	41.5	41.9	43.7	44.1	44.9	45.0	48.2	. .
44.5	31.9	41.8	42.2	44.0	44.3	45.1	45.3	48.4	. .
44.0	32.2	42.0	42.4	44.2	44.6	45.5	45.6	48.7	. .
43.5	32.4	42.3	42.6	44.5	44.8	45.7	45.9	49.0	. .
43.0	32.7	42.6	42.9	44.8	45.1	46.0	46.1	49.3	. .
42.5	32.9	42.9	43.2	45.0	45.4	46.3	46.4	49.6	. .
42.0	33.2	43.1	43.5	45.3	45.6	46.5	46.7	49.9	. .
41.5	33.5	43.4	43.7	45.6	45.8	46.8	47.0	50.1	. .
41.0	33.7	43.7	44.0	45.9	46.1	47.0	47.3	50.4	. .
40.5	34.0	43.9	44.2	46.1	46.3	47.3	47.6	50.7	. .
40.0	34.3	44.2	44.5	46.4	46.6	47.6	47.8	51.0	51.6
39.5	34.5	44.5	. .	46.6	46.8	47.8	48.1	51.3	51.8
39.0	34.8	44.8	. .	46.8	47.1	48.1	48.4	51.6	52.1
38.5	35.0	45.0	. .	47.1	47.4	48.4	48.7	51.9	52.4
38.0	35.3	45.3	. .	47.4	47.6	48.6	48.9	52.1	52.6
37.5	35.5	45.6	. .	47.6	47.8	48.9	49.2	52.4	52.8
37.0	35.8	45.9	. .	47.9	48.1	49.2	49.5	52.7	53.1
36.5	36.1	46.1	. .	48.2	48.3	49.4	49.8	53.0	53.4
36.0	36.3	46.4	. .	48.5	48.6	49.7	50.0	53.3	53.7
35.5	36.6	46.7	. .	48.7	48.8	50.0	50.3	53.6	54.0
35.0	36.9	47.0	. .	49.0	49.1	50.2	50.6	53.9	54.2
34.5	37.1	47.2	. .	. .	. .	. .	50.9	54.2	54.5
34.0	37.4	47.5	. .	. .	. .	. .	51.2	54.4	54.7
33.5	37.6	47.8	. .	. .	. .	. .	51.5	54.7	55.0
33.0	37.9	48.1	. .	. .	. .	. .	51.7	55.0	55.3
32.5	38.1	48.3	. .	. .	. .	. .	52.0	55.3	55.6
32.0	38.4	48.6	. .	. .	. .	. .	52.3	55.6	55.9
31.5	38.6	48.9	. .	. .	. .	. .	52.6	55.9	56.1
31.0	38.9	49.2	. .	. .	. .	. .	52.8	56.1	56.4
30.5	39.2	49.5	. .	. .	. .	. .	53.1	56.4	56.7
30.0	39.5	49.8	. .	. .	. .	. .	53.4	56.7	57.0
29.5	39.7	50.0	. .	. .	. .	. .	53.7	57.0	57.2
29.0	40.0	50.3	. .	. .	. .	. .	53.9	57.3	57.5
28.5	40.3	50.5	. .	. .	. .	. .	54.1	57.6	57.8
28.0	40.5	50.8	. .	. .	. .	. .	54.4	57.8	58.1
27.5	40.8	51.1	. .	. .	. .	. .	54.7	58.1	58.3
27.0	41.0	51.4	. .	. .	. .	. .	55.0	58.4	58.6
26.5	41.3	51.6	. .	. .	. .	. .	55.2	58.7	58.9
26.0	41.5	51.9	. .	. .	. .	. .	55.5	59.0	59.2
25.5	41.8	52.2	. .	. .	. .	. .	65.8	59.3	59.5
25.0	42.0	52.5	. .	. .	. .	. .	66.1	59.6	59.8

[1] Butter readings, by Zeiss.

[2] Lard readings, by Hefelmann.

TABLE II. — CALCULATED READINGS (continued).

TEMP. C.	OLIVE OIL.[1]	PEANUT OIL.	COTTON-SEED OIL.[2]	RAPE-SEED OIL.	SESAME OIL.	YELLOW MUST. OIL.	BLACK MUST. OIL.	SUN-FLOWER OIL.	CORN OIL.	POPPY-SEED OIL.
35.0	57.0	59.8	61.8	62.1	62.3	63.0	64.2	64.5	65.0	65.5
34.5	57.2	60.0	62.1	62.4	62.5	63.3	64.5	64.8	65.3	65.8
34.0	57.4	60.3	62.3	62.7	62.8	63.6	64.8	65.1	65.6	66.1
33.5	57.7	60.6	62.5	63.0	63.1	63.9	65.1	65.4	65.9	66.4
33.0	58.0	60.9	62.8	63.3	63.4	64.1	65.3	65.7	66.2	66.7
32.5	58.3	61.1	63.0	63.6	63.7	64.4	65.6	66.0	66.5	67.0
32.0	58.5	61.4	63.2	63.8	64.0	64.7	75.9	66.3	66.8	67.3
31.5	59.0	61.7	63.6	64.1	64.3	65.0	66.2	66.6	67.1	67.6
31.0	59.2	62.0	64.0	64.4	64.6	65.3	66.5	66.9	67.4	67.9
30.5	59.5	62.2	64.2	64.7	64.9	65.6	66.8	67.2	67.7	68.2
30.0	59.9	62.5	64.5	65.0	65.1	65.8	67.0	67.5	68.0	68.5
29.5	60.1	62.8	64.9	65.3	65.4	66.1	67.3	67.7	68.2	68.7
29.0	60.3	63.1	65.1	65.6	65.7	66.4	67.6	68.0	68.5	69.0
28.5	60.6	63.3	65.3	65.9	66.0	66.7	67.9	68.3	68.8	69.3
28.0	60.9	63.6	65.7	66.1	66.2	66.9	68.1	68.6	69.1	69.6
27.5	61.1	63.9	66.0	66.4	66.5	67.2	68.4	68.9	69.4	69.9
27.0	61.5	64.2	66.5	66.7	66.8	67.5	68.7	69.2	69.7	70.2
26.5	62.0	64.4	67.0	67.0	67.1	67.8	69.0	69.5	70.0	70.5
26.0	62.2	64.7	67.3	66.3	67.4	68.0	69.2	69.8	70.3	70.8
25.5	62.4	65.0	67.5	67.6	67.7	68.3	69.5	70.1	70.6	71.1
25.0	63.0	65.3	67.9	67.8	67.9	68.6	69.8	70.4	70.9	71.4
24.5	63.3	65.5	68.2	68.1	68.2	68.9	70.1	70.7	71.2	71.7
24.0	63.6	65.8	68.5	68.4	68.5	69.2	70.4	71.0	71.5	72.0
23.5	63.9	66.1	68.8	68.7	68.8	69.5	70.7	71.3	71.8	72.3
23.0	64.2	66.4	69.1	69.0	69.1	69.7	70.9	71.6	72.1	72.6
22.5	64.5	66.6	69.4	69.3	69.4	70.0	71.2	71.9	72.4	72.9
22.0	64.8	66.9	69.7	69.7	69.7	70.3	71.5	72.2	72.7	73.2
21.5	65.1	67.1	70.0	70.0	70.0	70.6	71.8	72.5	73.0	73.5
21.0	65.4	67.4	70.3	70.3	70.3	70.9	72.1	72.8	73.3	73.8
20.5	65.7	67.7	70.6	70.6	70.5	71.2	72.4	73.1	73.6	74.1
20.0	66.0	68.0	70.9	70.8	70.8	71.4	72.6	73.4	73.9	74.4
19.5	66.3	68.2	71.2	71.1	71.1	71.7	72.9	73.6	74.1	74.6
19.0	66.6	68.5	71.5	71.4	71.4	72.0	73.2	73.9	74.4	74.9
18.5	66.9	68.8	71.8	71.7	71.7	72.3	73.5	74.2	74.7	75.2
18.0	67.2	69.1	72.1	72.0	72.0	72.6	73.8	74.5	75.0	75.5
17.5	67.5	69.3	72.4	72.3	72.3	72.9	74.1	74.8	75.3	75.8
17.0	67.8	69.6	72.7	72.6	72.5	73.1	74.3	75.1	75.6	76.1
16.5	68.1	69.9	73.0	72.9	72.8	73.4	74.6	75.4	75.9	76.4
16.0	68.4	70.2	73.3	73.2	73.1	73.7	74.9	75.7	76.2	76.7
15.5	68.7	70.5	73.6	73.5	73.4	74.0	75.2	76.0	76.5	77.0
15.0	68.9	70.8	73.8	73.8	73.7	74.3	75.5	76.3	76.8	77.3

[1] Olive oil readings, by A. E. Leach.

[2] Cottonseed oil readings, by A. E. Leach.

The refraction of beef stearine could not be read at 35° as it melts at a higher temperature, but its refraction has been calculated to 35° for convenience in comparison. These figures agree very closely with figures of other writers, except in the case of peanut oil, in which a marked difference occurs. Lewkowitsch[1] gives the reading at 25° as 66–67.5, in the neighborhood of cottonseed oil, while Utz[2] gives it at the same temperature as 63.2, in the neighborhood of olive oil.

The writer found three samples of peanut oil of known purity to read 64.9, 65.0 and 65.3, respectively, at a temperature of 25° C., and it is from these oils that the readings for Table II have been calculated.

In Table II the readings of the solid fats are given from 25°, or from the melting points if above this, to 45°, and the liquid oils are given from 15° to 35° C.

The constants of a few of the oils are as follows:

TABLE III.—CONSTANTS FOR CERTAIN OILS.

	BUTYRO-REF. AT 35°.	IODINE NUMBER.	SPEC. GRAV.
Beef Stearine,	47.0 (calculated)	27.17	0.9510
Lard Stearine,	50.2	43.49	0.9496
Beef Oleo,	50.6	50.67	0.9256
Lard Oil,	54.2	70.04	0.9146

[1] Fats, oils and waxes.

[2] Apoth. Zeit, 1900, 15, p. 651; Abstract in Zeit. Unters, Nahr und Genuss, 1901, p. 453.

THE SIGNIFICANCE OF BACTERIOLOGICAL METHODS IN SANITARY WATER ANALYSIS.

By C.-E. A. WINSLOW and C. P. NIBECKER.

1. *Sanitary Inspection and Its Limitations.* — It is well recognized today that a study of the possible sources of pollution on a watershed, of the direction and velocity of currents above and below ground, of the character of soil and the liability to contamination by surface wash, may furnish the expert with evidence of the greatest value. Often, however, he must form some opinion upon the quality of water sent from a distance without the opportunity of examining its surroundings; and even when a sanitary inspection can be made its results are by no means conclusive. No reconnoissance can show certainly whether unpurified drainage from a cesspool does or does not reach a given well; whether sewage discharged into a lake does or does not find its way to a neighboring intake; whether pollution of a stream has or has not been removed by a certain period of flow. Evidence upon these points must be obtained from a careful study of the characteristics of the water in question, and this study can be carried out along two lines, chemical and bacteriological.

2. *The Significance of the Chemical Analysis.* — A chemical examination of water for sanitary purposes is mainly useful in throwing light upon one point — the amount of decomposing organic matter present. Humus-like substances may be abundant in surface waters quite free from harmful pollution, but these are stable compounds. Easily decomposable bodies, on the other hand, must obviously have been recently introduced into the water, and mark a transitional state. "The state of change is the state of danger," as Dr. T. M. Drown has phrased it. Sometimes the organic matter has been washed in by rain from the surface of the ground; sometimes it has been introduced in the concentrated form of sewage. In any case, it is a warning of possible pollution, and the determination of free ammonia, nitrites, carbonaceous matter as shown by "oxygen consumed," and dissolved oxygen yield important evidence as to the sanitary quality of a water.

Furthermore, nitrates, the final products of the oxidation of organic matter, and the chlorine introduced as common salt into all water which has been in contact with the wastes of human life, furnish additional information as to the antecedents of a sample. The results of the chlorine determination are indeed perhaps more clear than those of any other sanitary process, for chlorine and sewage pollution vary together, due allowance being made for the proximity of the sea and other geological and meteorological factors. Unfortunately, it is only past history and not present conditions which these latter tests reveal, for in a ground water completely purified, from a sanitary standpoint, such soluble constituents remain, of course, unchanged. Thus, in the last resort, it is upon the presence and amount of decomposing organic matter in the water studied that the opinion of the chemist must be based.

3. *The Quantitative Bacteriological Examination of Water.* — The decomposition of organic matter may be measured either by the material decomposed or by the number of organisms engaged in carrying out the process of decomposition. The latter method has the advantage of far greater delicacy, since the bacteria respond by enormous multiplication to a very slight increase in their food supply, and this fact, which necessitates great care in methods and great caution in the interpretation of results, has led hasty observers to condemn the quantitative bacteriological methods. The past ten years have witnessed, however, remarkable progress, and the establishment of a procedure for the making of approximately uniform media, through the efforts of G. W. Fuller, G. C. Whipple and other prominent members of the American Public Health Association, has placed quantitative bacteriology on a reasonably firm basis.

The distinction between quantitative and qualitative bacteriological analysis is a somewhat arbitrary one. The gelatin plate is not only quantitative but also qualitative, inasmuch as it eliminates numerous bacteria for whose growth its conditions are unfavorable, and the dextrose broth tube is a quantitative as well as a qualitative test when it is applied to a series of measured portions of the water to be examined. A better classification would separate processes which indicate decomposing organic matter in general from those other methods which aim at the separation of the organisms associated more specifically with sewage pollution. Under the first head comes only the standard gelatin plate count at 20°; and this count, as above suggested, roughly

corresponds, in not too heavily polluted waters, to the free ammonia and "oxygen consumed," as revealed by chemical analysis. If low numbers of bacteria are found, the evidence is highly reassuring, for it is seldom that water could be contaminated under natural conditions without the direct addition of foreign bacteria or of organic matter which would induce a rapid multiplication of those already present. The bacteriologist, in such cases, can declare the innocence of the water with justifiable certainty. Recently an examination was made by one of us of a town supply which was derived from a filter gallery on the shore of a lake below a gathering ground occupied by a considerable population. Public confidence in this water had been shaken because the chlorine was high, about eight parts per million. It is true that the ammonias were fairly low, the free ammonia being about .03 parts and the albuminoid ammonia about .05 parts per million; but the gelatin count proved far more instructive. Plates made from water taken at different parts of the system showed from 0 to 5 colonies per cubic centimeter, indicating, in connection with sterile litmus-lactose-agar plates at 37° and negative tests for *Bacillus coli*, that at the time of examination all pollution had, without question, been effectually removed. Only repeated studies could, of course, prove this condition to be permanent, but the same objection applies to any other method of analysis.

If the gelatin count be high, the interpretation is less simple. In the first place, high numbers are at times due to the exceptional multiplication of certain water forms, which may generally be detected by inspection of the plates. Thus a sample of spring water recently received from a distance contained, on arrival, 4,200 bacteria per cubic centimeter, almost all the colonies being those of the fluorescent water bacillus. Sterile litmus-lactose-agar plates and negative tests for sewage bacteria confirmed the conclusion that in this case the high count signified only a multiplication in transit. Large numbers, under ordinary conditions, when they include a normal variety of forms, indicate, however, the presence of an excess of organic matter. Such organic matter may not mean sewage pollution; it does mean at least the presence of washings from the surface of the ground, which always implies the possibility of pollution; and no supplies exposed to such conditions are now considered satisfactory. The close correspondence between the excess of bacteria in surface waters during the winter and spring months, and the epidemics of typhoid fever due

to the same waters, brings out forcibly the reality of this danger, and emphasizes the fact that high total numbers of bacteria are always to be regarded as possibly significant.

4. *The Isolation of Intestinal Bacteria.* — The bacteriologist can, however, do more than detect the presence of general organic contamination; he can discover as well in polluted water certain semi-parasitic organisms, found in large numbers in the alimentary canal, whose presence specifically indicates the entrance of sewage. Ever since its interference with the early attempts to isolate the germ of typhoid fever from water the *Bacillus coli* has been recognized as an organism of this character, and in recent years the researches of the English sanitarians, A. C. Houston, E. Klein, and W. H. Horrocks, have shown the importance of the streptococci in the same connection.

This whole subject is a new one, and even in the technique of the colon test divergent opinions still exist on two points, which, it is to be hoped, may be harmonized for the sake of comparability. In the first place, the tests used in defining *Bacillus coli* are not yet quite uniform. For example, Whipple has recently[1] given forty-eight hours as the period for the nitrate, milk, and indol reactions; while twenty-four hours is the time employed in many laboratories for the two first, and seventy-two hours for the last of these tests. Whipple also includes the failure to form spores as one of the routine tests for *Bacillus coli*, which seems to us needless, as there are no forms likely to be found in water analyses which form spores while giving all the other reactions of the organism. These slight differences in method do not, however, materially affect the practical results of the colon test. The main characteristics of the bacillus, the typical reactions on agar and gelatin, and in dextrose broth, milk, nitrate solution, and peptone solution, are well understood; and the effect of the different periods used for the tests will only be manifest in the inclusion or exclusion of certain allied forms, which Whipple assumes, with some probability, to be typical colon bacilli, weakened by sojourn under unfavorable conditions. It seems to us desirable, in the present state of our knowledge, to exclude, as far as possible, these atypical forms, whose significance is still uncertain.

More serious than slight variations in the technique of the colon test is the failure to apply it quantitatively to the examination of small samples of water, cubic centimeters or fractional parts. *Bacillus coli* has frequently been found in large samples of waters of fair sanitary

quality. Prescott[2] has shown the identity of this organism with certain lactic acid bacteria found upon grains and other cereals. Whipple remarks that, "*Bacillus coli*, if not widely distributed in nature, resembles certain common bacteria in all points covered by the usual tests;" but it by no means follows, as he states, that this throws "doubt upon the use of this organism as a conclusive test for fæcal contamination." Many German bacteriologists, particularly the pupils of Kruse, at Bonn, have indeed concluded, because they could isolate colon bacilli from good waters by the examination of a series of liter samples, that the test was valueless. It is essentially, however, a question of less and more. Colon bacilli are either wanting in good waters or are so rare as not to be found in the examination of samples of one cubic centimeter; they are found in a majority of one cubic centimeter samples of water so polluted as to be dangerous for drinking; between these two extremes their numbers vary with the amount of pollution. Klein and Houston[3] in England, Jordan,[4] and Winslow and Hunnewell[5] in America, and very recently, Petruschky and Pusch[7] in Germany, have exhaustively studied the distribution of the colon bacillus with uniform results. That the absence of this organism demonstrates the harmlessness of a water as far as bacteriology can prove it no one would probably hesitate to acknowledge; and that, when present, its numbers form a trustworthy measure of its sanitary condition, the observers above quoted have proved beyond reasonable cavil.

5. *The Fermentation Test.* — In a thorough examination of a single sample of water the attempt should be made to isolate colon bacilli and streptococci, and to work them out in detail. Often, however, when a quick result is desired, or when a long series of routine observations must be made, some shorter method is desirable. The classic work of Theobald Smith early pointed out that the dextrose broth tube furnished such a rapid test,[6] and it has since been well established that organisms found in water which at 37° produce in twenty-four hours a good quantity of gas, made up of approximately two parts of hydrogen to one part of carbon dioxide, are almost always colon bacilli. In the paper to which reference has several times been made, Whipple[1] has brought strong evidence of the value of this, which he calls the "presumptive test" for *Bacillus coli*. The diagrams there given, showing the chemical and bacteriological relation of certain surface waters grouped under six headings, according to their relative pollution as determined by inspection, are striking, and indicate that the presump-

tive colon test harmonizes closely with actual conditions. Whipple's scale, according to which water giving a positive presumptive test in one cubic centimeter is questionable and in one-tenth of a cubic centimeter is probably unsafe, seems justified by all the evidence at hand.

6. *The Litmus-Lactose-Agar Plate.* — Besides the gelatin plate count at 20° and the study of dextrose broth tubes, either with determination of the gas formula alone or with sub-cultures definitely to identify the colon bacillus and the streptococci, there is another method of examination — the direct plating of the water in litmus-lactose-agar, — which has never come into such general use, but which is capable of wide and helpful application. Hazen and White,[8] as long ago as 1891, suggested that agar plates grown at the body temperature, instead of permitting the growth of all the water species, would "present a selected number, namely, those which can live at blood heat; including, we may believe, most of the parasitic and pathogenic germs, which, under the circumstances, are the ones of greatest interest; and eliminating those species which cannot grow at the temperature of the body, and are, therefore, in most cases, as such, presumably harmless."

In 1893, Mathews,[9] now so widely known for his physiological researches, published in this journal an account of the Wurtz litmus-lactose-agar plate, introduced into this country in the previous year by Professor Sedgwick and himself, and suggested its application to the sanitary analysis of water. Fifty-nine samples of water examined gave results summarized in the following table, indicating clearly what the author described as a "heat and agar differentiation."

Sources of Water.	Average Number of Colonies per c.c.	
	Gelatin 20°.	Wurtz-Agar 37.5°.
Wells, springs	1,664	28
Reservoirs	153	43
Ponds	296	95
Taps	242	24
Streams	273	101

The main object of this work was to facilitate isolation of the typhoid bacillus from water by eliminating those forms likely to mask it

on the gelatin plate. It was obvious, however, that a method giving such special prominence to organisms growing at the body temperature and to the acid formers, which have more and more come to be recognized as intestinal forms, must have a direct application to sanitary water analysis.

The general interest awakened about 1893 by the colon test perhaps accounts for the fact that the agar plate method was used less for its own sake than as an aid in the separation of *Bacillus coli*. It has been extensively applied to this purpose by the Massachusetts State Board of Health; in 1899 the average number of colon bacilli in the Merrimac River water thus determined varied from eight per c.c. in August to 140 in December.[10] Irons,[11] at about the same time, compared the method with the dextrose broth tube for the isolation of *Bacillus coli*, and concluded that it was less useful than the latter, especially when applied to highly polluted waters.

English sanitarians have made good use of this test, modified by the addition of one-thousandth part of phenol to the litmus-lactose-agar medium. The elaborate researches of Chick,[12] for example, showed 6,100 colon bacilli per c.c. in the Manchester Ship Canal, 55–190 in the polluted River Severn, and numbers up to 65,000 per gram in roadside mud. On the other hand, of thirty-eight unpolluted streams and rivulets, thirty-one gave no *Bacillus coli*, and the other seven gave one per cubic centimeter or less. The Liverpool tap water, snow, rain, and hail gave no colon bacilli.

Few recent authors appear to have used the 37° count and the count of acid formers as in themselves important, although Rideal[13] lays some stress upon the former and mentions that a London water gave on an average only one-twelfth as many colonies on agar at 37° as on gelatin at 20°. The blood temperature count has, however, been in constant use in the biological laboratories of the Massachusetts Institute of Technology, at the University of Chicago, at Beloit College and some other institutions, and in legal practice, with results of uniform significance.

7. *New Studies of Unpolluted Waters by means of the Litmus-Lactose-Agar Plate.* — We are strongly of the opinion that this feature of the bacteriological analysis should not be neglected, particularly in view of the fact that the litmus-lactose plate reveals the presence of the streptococci which may be overlooked in the dextrose tube. Because of the small attention paid to the method in recent text-books and the

paucity of published data as to its results, we have thought it worth while to repeat Mathews's work of 1893 by the examination of 259 samples of water. The samples covered as wide a range as possible of waters presumably not polluted by sewage, our object being to show definitely whether organisms growing at 37° and fermenting sugar are rare in such sources. Besides the public supplies of thirteen cities and towns, we examined waters from brooks, ponds, springs, deep and shallow wells, swamps, and pools in fields and woods. The samples were collected between January and May of 1903, and in some instances the spring rains had washed excessive amounts of organic matter into the waters tested. In most cases the samples were brought to the laboratory within four to six hours, and two gelatin plates, two litmus-lactose-agar plates, and three dextrose broth tubes were inoculated from each, one cubic centimeter portions being used, or one-tenth of a cubic centimeter portions in plating from those samples which contained an obvious excess of organic matter. The agar plates were counted after twenty-four hours at 37°, the number of red colonies being noted, and at the same time the dextrose broth tubes were examined and the gas formula determined. The gelatin plates were counted after forty-eight hours.

8. *Results of Our Studies.* — The results of the examination are shown in detail upon the accompanying table. The gelatin counts, it will be noted, ranged high in some cases: the Dedham, Medford, and Milton supplies, the Sharon well, the roadside pools, and the drainage from a pasture giving figures which would excite suspicion. The high Milton figures may probably be explained by the fact that these samples were two to three days old when examined, a condition which obtained in no other case. The Dedham average was due to very high counts on two samples, the other plates being sterile.

The total count on litmus-lactose-agar was, in general, low, the highest average being 46 for the Sharon well and 31 for the pools in the fields. The general average for the whole 259 samples was less than 8. Colonies of strong red color were found in only two samples, one from the Sharon well and one from the Brookline supply. In the latter case, we have reason to suspect contamination after the collection of the sample and while it was out of our hands. A very faint acid producer, giving a mere suggestion of red color, was present in a number of the public supplies, and proved to be *Bacillus mycoides*, or a closely related form. Finally, of the dextrose broth tubes

EXAMINATION OF 259 SAMPLES OF WATER FROM APPARENTLY UNPOLLUTED SOURCES.

Source of Samples.	Number of Samples.	Gelatin Plates.				Litmus-Lactose-Agar Plates.					Dextrose Broth Tubes.			
		Number of plates.	Maximum number of colonies.	Minimum number of colonies.	Average number of colonies.	Number of plates.	Maximum number of colonies.	Minimum number of colonies.	Average number of colonies.	Plates showing red colonies.	Number of tubes.	Number of tubes with gas.	Number of tubes with gas 1-0.	Number of tubes with gas 2-1.
Cambridge supply (tap).	5	10	240	20	94	8	15	2	11	0	15	0	0	0
Wakefield and Stoneham supply (tap).	7	14	150	20	59	13	12	2	6	0	21	0	0	0
Lynn supply (tap).	6	12	20	0	16	12	6	1	3	0	18	0	0	0
Brookline supply (tap).	1	2		all liquefied		2	21	15	18	2	3	0	0	0
Plymouth supply (tap).	6	12	70	10	35	12	6	0	2	0	18	0	0	0
Peabody supply (tap).	3	6	261	30	141	5	36	1	21	0	9	2	2	0
Dedham supply (tap).	6	12	13,500	0	3,717	11	3	0	1	0	18	0	0	0
Newburyport supply (tap).	6	12	100	10	36	12	14	2	9	0	18	0	0	0
Salem supply (tap).	5	10	267	200	232	10	23	10	14	0	15	0	0	0
Taunton supply (tap).	4	7	41	10	13	8	5	0	2	0	12	0	0	0
Sharon (well) (tap).	3	6	845	630	738	6	74	30	46	2	9	3	0	3
Medford supply (tap).	5	10	1,250	240	524	10	16	3	8	0	15	0	0	0
Milton supply (tap).	2	4	5,000	4,200	4,700	4	0	0	0	0	6	0	0	0
Westerly, R. I., supply (tap).	1	2		all liquefied		2	13	12	12	0	3	0	0	0
Brooks.	61	122	1,010	30	223	121	83	0	7	0	183	13	13	0
Driven wells.	15	30	54	0	18	30	5	0	1	0	45	0	0	0
Springs.	32	64	1,270	20	294	64	13	0	2	0	96	13	13	0
Ponds fed by brooks.	15	30	340	100	167	30	24	0	9	0	45	1	1	0
Melted snow.	1	2		all liquefied		2	5	3	4	0	3	0	0	0
Pools in fields.	22	44	760	100	365	44	95	2	31	0	66	2	2	0
Pools in woods.	22	44	580	10	181	43	14	0	3	0	65	0	0	0
Roadside pools.	10	20	9,000	410	811	20	10	0	4	0	30	2	2	0
Stream, Blue Hill Reservation.	1	2		all liquefied		2	0	0	0	0	3	0	0	0
Flow from rocks.	2	4	60	30	47	4	2	0	0	0	6	0	0	0
Ponds fed by springs.	6	12	420	60	188	12	5	0	2	0	18	0	0	0
Drainage from manured pasture.	1	2	1,270	1,200	1,235	2	28	26	27	0	3	0	0	0
Swamps.	3	6	310	240	269	6	10	0	6	0	9	5	5	0
Rain water, after twelve hours' heavy fall.	7	14		all liquefied		14	6	0	2	0	21	0	0	0
Shallow well in Lynn Woods.	1	2	20	10	15	2	1	1	1	0	3	0	0	0
Totals,	259	517				511				4	775	41	38	3

inoculated, only forty-one showed gas, and of these, only three, made from the Sharon well, gave the proper gas formula. The organism here actually proved to be *Bacillus coli;* and as the well is situated just below a stable and barnyard we are inclined to believe it actually polluted. Thus this apparent exception only adds to the force of the general rule.

If we consider the results of this examination of the litmus-lactose-agar plate it becomes apparent that organisms capable of growth at the body temperature are not numerous in unpolluted waters; acid formers are practically absent.

We have made no special comparative examinations of polluted waters because their condition is fairly well known. The Massachusetts State Board of Health results, and those obtained by Chick for *Bacillus coli* alone, are sufficiently large to give an idea of the number of acid formers present in polluted streams; while in some recent work at the Institute, to be published shortly, Mr. S. K. Baker has found total 37° counts ranging from 9,800 to 16,900 in water from various parts of the Charles River. Two twenty-four-hour examinations of Boston sewage, made at the Sanitary Research Laboratory of the Massachusetts Institute of Technology during the summer of 1903, gave an average of 3,660,000 bacteria per c.c. on gelatin at 20°, and 2,310,000 bacteria per c.c. on lactose-agar at 37°, with 550,000 acid formers. In general, we may say that the total count on litmus-lactose-agar will be likely to run into hundreds in polluted waters, sometimes equalling that obtained on gelatin at 20°, with a large proportion of acid formers; while good waters will show a count under fifty, with acid formers only rarely present. From exceptionally pure waters sterile plates at 37° may often be obtained.

9. *Summary of Bacteriological Methods.* — In conclusion, it appears, in the light of present knowledge, that the full bacteriological examination of the future will consist of three parts — the gelatin plate count as an estimate of the amount of organic decomposition in process; the total count and the count of red colonies on litmus-lactose-agar, as a measure of the organisms which form acids and thrive at the body temperature; and the study of a series of dextrose broth tubes for the isolation of colon bacilli and streptococci. The simple examination of the dextrose broth tube and the count on the litmus-lactose-agar plate will serve for what Whipple has well called presumptive tests.

10. *Significance of Bacteriological Results.* — The results of the bacteriological examination have, in several respects, a peculiar and unique significance. First, this examination is the most direct hygienic method of water analysis. Whipple,[1] in the paper quoted above, says that his presumptive test "gives results that agree well with chemical and biological analysis." Bacteriology, however, needs no such indirect justification. What we dread in drinking water is the presence of pathogenic bacteria, mainly from the intestinal tract of man, and it is quite certain that the related non-pathogenic bacteria from the same source will reveal the presence of these disease germs more clearly than will any chemical compounds. In the second place, the bacteriological methods are far more delicate than any others. Klein[8] showed by experiment with dilutions of sewage that the colon test was from ten to one hundred times as sensitive as the methods of chemical analysis; and a simple calculation shows that this must be the case, since sewage contains only from a hundred to a thousand times as much chlorine as good drinking water against ten thousand to a hundred thousand times as many colon bacilli. Studies of the self-purification of streams have confirmed these conclusions on a practical scale. Thus in the Sudbury River it was found that while the chemical evidences of pollution persisted for six miles beyond the point of entrance, the bacteria introduced could be detected for four miles further.[14] Thirdly, negative tests for *Bacillus coli* and low bacterial counts may be interpreted as proofs of the good quality of water, with a certainty not attainable by any other method of analysis. Many a surface water with reasonably low chlorine and ammonias has caused epidemics of typhoid fever; but it is impossible, under any natural conditions, that a water could contain important typhoid contamination without giving clear evidence of pollution in the dextrose broth tube or on the lactose-agar plate.

It seems to the writers that the real application of chemistry begins where that of bacteriology ends. When pollution is so gross that its existence is obvious and only its amount needs to be determined, the bacteriological tests will not serve on account of their excessive delicacy. In studying the heavy pollution of small streams, the treatment of trades wastes, and the purification of sewage, the relations of nitrogenous compounds and of oxygen compounds are of prime importance. In other words, when pollution is to be avoided because the decomposition of chemical substances causes a nuisance, it must be studied by chemical methods. When the danger is of infection and comes

only from the presence of bacteria, bacteriological methods furnish the best index of pollution.

In the study of certain special problems the paramount importance of bacteriology is generally recognized. The distribution of sewage in large bodies of water into which it has been discharged may be traced best in this way on account of the ready response of the bacterial counts to slight proportions of sewage, particularly since the ease and rapidity with which the technique of plating can be carried out make it possible to examine a large series of samples with a minimum of time and trouble. For the same reasons, and because the factors which condition the disappearance of disease germs from a polluted river must operate most nearly in the same manner upon related parasitic forms, the fermentation tube and the gelatin and lactose-agar plates furnish the best criteria for a study of the self-purification of streams. Finally, the quickness with which slight changes in the character of a water are marked by fluctuations in bacterial numbers renders the bacteriological methods invaluable for the daily supervision of surface supplies or of the effluents from municipal filtration plants.

In the commoner case, when normal values obtained by such routine analyses are not at hand, the problem of the interpretation of any sanitary analysis is a more difficult one. The conditions which surround a source of water supply may be constantly changing. No engineer can measure the flow of a stream in July and deduce the amount of water which will pass in February. Yet the July gauging has its own value and significance. So a single analysis of any sort is not sufficient for all past and future time. If it gives a correct picture of the hygienic condition of the water at the moment of examination, it has fulfilled its task; and this the bacteriological analysis can do. The evidence furnished by inspection and by chemical analysis must be welcomed whenever it can be obtained. Yet we are of the opinion that, on account of their directness, their delicacy, and their certainty, the bacteriological methods should be the last to be omitted, and, if necessary, they alone may furnish conclusive testimony as to the safety of a potable water.

In conclusion, we desire to express our thanks to Professor W. T. Sedgwick, whose interest in this subject has been our chief inspiration, as it was that of some of its earliest investigators in 1891 and 1893.

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The Biological Laboratories,
Massachusetts Institute of Technology.

STRUCTURE AND COMPOSITION OF THE DELTA PLAINS FORMED DURING THE CLINTON STAGE IN THE GLACIAL LAKE OF THE NASHUA VALLEY.[1]

By W. O. CROSBY.

Introduction.

During the Clinton stage of Lake Nashua the impounded waters found an outlet through the pass in the eastern wall of the valley now occupied by the Central Massachusetts Railroad and later to be closed by the South Dike (one of the auxiliary dams of the Wachusett Reservoir), and were probably tributary to the Charles River and Massachusetts Bay, as described in the preceding paper.[2] The normal elevation of this outlet is about 370 feet, or about 70 feet lower than the outlet southward into Lake Quinsigamond and the Blackstone River during the earlier, Boylston, stage. Since the South Dike pass is the lowest point in the rim of the Nashua Valley south of Ayer Junction and the Fitchburg Railroad, more than a dozen miles to the northward, we may fairly assume that the Clinton stage of Lake Nashua was the longest in its history. Certainly in no other part of the valley have the delta plains a more perfect or more continuous development. As

[1] This paper will complete the series of contributions to the geology of the Nashua Valley, in Massachusetts, based upon the studies and observations made by the writer in connection with the operations of the Metropolitan Water Board in the construction of the Wachusett Reservoir and Aqueduct. The first paper, on the "Geology of the Wachusett Dam and Wachusett Aqueduct Tunnel" (Technology Quarterly, Vol. XII, 68–96), relates especially to the character and structural relations of the rock formations of a limited portion of the eastern side of the valley; the second paper, on the "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods" (Technology Quarterly, Vol. XII, 288–324), is essentially a physiographic study of the region, considering especially the history of the drainage and the successive stages of glacial Lake Nashua; and the purpose of this third paper is a detailed account of some of the deposits formed during a single stage of Lake Nashua. Once more I feel myself deeply indebted to the Metropolitan Water Board for the opportunity to do this work and for permission to publish the results of scientific interest, and my grateful acknowledgments are also due the chief engineer of the board, Mr. F. P. Stearns, and various members of his staff for many special facilities and helpful courtesies in the prosecution of the work.

[2] Technology Quarterly, 12, 318.

previously noted,[1] however, the plains of this stage belong almost wholly to its earliest phase, when the water area was small, occurring chiefly in Boylston and Clinton and almost wholly south of Lancaster, suggesting that over the long stretch of the valley between Clinton and Ayer the ice margin retreated too rapidly to permit the formation of extensive plains of normal height in water from 100 to 200 feet deep. Although, as the accompanying map shows, the Clinton plains, with normal elevations of 375 to 385 feet, are broadly and typically developed in the districts both immediately northwest and southwest of the village of Clinton, it is in the latter area that they have been most perfectly exposed for study by deforesting, and most fully explored, first, by drilling, preparatory to the construction of the North Dike, and second, by the excavation of the great trench subsequently filled with impervious material to form the core, or cut-off, of the dike. The main cut-off trench afforded a nearly continuous section, having an aggregate length of 9,556 feet and a maximum depth of 60 feet, and in addition to this there was a shorter secondary cut-off trench. The wash-drill borings, to the number of 1,131, with an average depth of 83 feet and a maximum depth of nearly 300 feet, are distributed systematically and somewhat uniformly over an area 9,000 feet in length (east-west) and 2,000 to 3,000 feet in breadth. Nearly 10,000 samples from these borings have been examined, in part somewhat exhaustively, and it is, perhaps, within bounds to say that in certain aspects no similar body of modified drift has been more thoroughly investigated. The available data seem, therefore, to justify a somewhat elaborate description and discussion — especially when taken in connection with the fact, fully brought out by the borings, that these delta deposits fill and deeply bury the preglacial gorge of the Nashua River and have thus, for this region, very exceptional thickness; and the further fact that externally, also, they are rather impressive examples of the type, presenting ideal developments of all the normal features, including ice contact, frontal and erosion slopes, and the plain upper or top-set surface dimpled by kettles. Moreover, tributary eskers are not wholly wanting, notwithstanding the great average depth of the water in which the deltas were built.

The plan of this paper embraces, then, a brief account of the external and formal features of the Clinton deltas, followed by the more

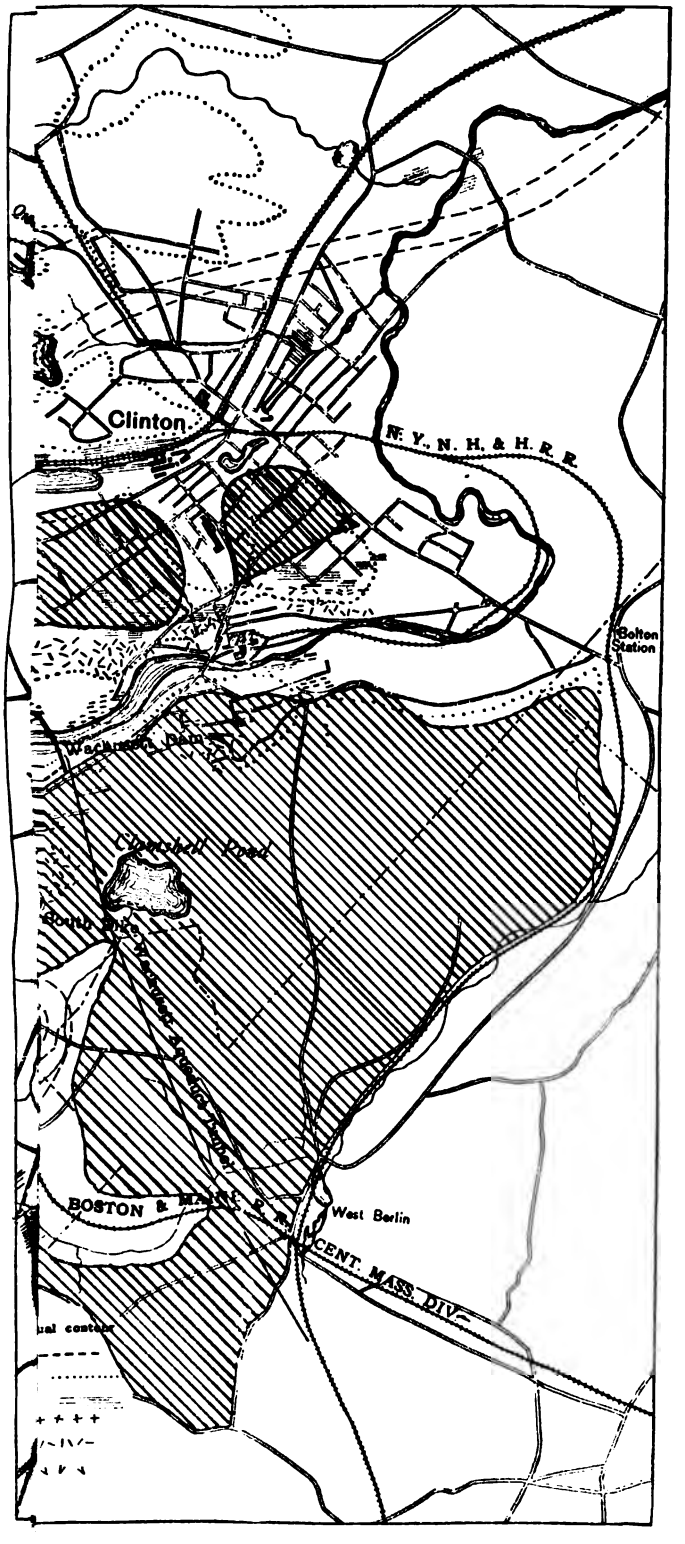
[1] TECHNOLOGY QUARTERLY, 12, 323.

minute and elaborate description and discussion of structure and composition indicated in the title; and its publication is not lacking in timeliness, since the borings and excavations are completed, while the natural contours of a large area have been effaced by the building of the North Dike, and all that part of the deltas south of the North Dike will be permanently submerged within the next five years by the filling of the great reservoir.

Formal Features of the Clinton Plains.

Recessional Development and Original Subdivision. — Narrow marginal developments, mainly erosion remnants of plains coinciding in elevation with the Clinton delta, terrace the Nashua Valley as far up as Oakdale, where the Nashua is formed by the confluence of the Stillwater and Quinepoxet Rivers. Each of the marginal developments promptly rises above the Clinton level. It is probable, however, that these are not to any important extent the product of free delta growth at this level, but they may be ascribed in the main, if not wholly, to the erosive action of the river as it cut down through the plains of the preceding, or Boylston, stage and developed its flood plains at the base level determined by the South Dike or Clinton outlet of Lake Nashua, as described in an earlier paper.[1] In other words, during the Boylston stage the entire valley above the ice margin, which was then in the latitude of Boylston (Sawyer's Mills), was probably, except where occupied by residuary masses of ice, completely filled by the Boylston deposits to the level of that stage (440 feet), leaving no room south of the Boylston ice margin for the extension of the later Clinton plains. And with the opening of the South Dike pass came a rapid development of the Clinton plain, made possible by the necessarily rapid erosion of the high and deep deposits of the Boylston stage. In fact, the waste of the Boylston plain along the axis of the valley must have been enormous in the first few years after it became exposed to the rush of the Nashua and its tributaries, with a fall of from 10 to 20 feet per mile, and we cannot escape the conclusion that through the coöperation of the Nashua with the glacial streams from the northward the Clinton plain was developed continuously along the southern margin of the ice to the outlet, the level of

[1] Technology Quarterly, 12, 320.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N. Y., N. H. & H. R. R.
Bolton Station
Wachusett Dam
Wachusett Aqueduct
BOSTON & MAINE R. R.
West Berlin
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which was probably raised somewhat by the extension through it of the coarse top-set layers of the delta.

The marked narrowing of the valley at Boylston, so well indicated on the map by the flow line of the reservoir, is due chiefly to a broad and well-preserved remnant of the Boylston plain, with the full normal elevation of 440 feet, which juts into the valley from the southward, terminating on the northwest in a well-marked erosion slope rising abruptly nearly 150 feet above the river, and on the northeast in an irregular but typical ice-contact slope, with tributary eskers, overlooking the Clinton plains. The narrowing of the valley at this point is due in part, also, to the protrusion into it from the northward of the high level marginal plain of the early Clinton stage, as described in the preceding paper.[1]

Above this constriction we find, below the Boylston level, first, the narrow and discontinuous marginal plains or terraces of the Clinton level, due to the erosion of the Boylston plains by the Nashua River during the Clinton stage, when the base level was controlled by the South Dike outlet; and second, the flood plains of the modern Nashua, due to the further erosion of the Boylston deposits during the time that the base level in this part of the valley has been determined by the ledge of slate over which the river now flows at Boylston.

Below the constriction, on the other hand, are the broad deltas of the Clinton stage, divided at a level some 80 feet lower by the flood plains of the modern river, due to the erosion of the Clinton deposits during the time that the base level in this part of the valley has been determined by the ledge of granite forming the bed of the river at the Lancaster mills in Clinton.

Immediately below Boylston the valley widens rapidly where it intersects the valleys of the ancient Wachusett River and its tributaries,[2] and this intersection of the ancient and modern drainage affords a ready explanation at once of the exceptional width and of the complexity of this part of the valley, in which the Clinton plains are developed almost exclusively.

As the map so clearly shows, the Clinton plains terminate on the east and west against slopes of rock and till, and on the south against the ice-contact slope and eskers of the Boylston plain. Although it

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[1] TECHNOLOGY QUARTERLY, 12, 318.

[2] TECHNOLOGY QUARTERLY, 12, 309.

appears impossible to escape the conclusion that the earlier, or southern part, at least, of the Clinton plain was formed largely of material derived by the rapid fluvial erosion of the Boylston plain, we find along the main part of this margin, and especially at the base of the best developed portion of the Boylston plain, a well-marked foss, or depression, which is, however, more or less discontinuous, consisting of a series of kettles and basins clearly indicative of buried masses of ice rather than of a failure of the Clinton delta to fill its basin in this direction, and testifying to the promptness with which deposition,

FIG. 1. — VIEW OF THE EASTERN END OF THE NORTH DIKE PLAIN, LOOKING NORTHWEST ACROSS THE NASHUA RIVER AT THE GREAT BEND, WITH BURDETTE HILL IN THE RIGHT DISTANCE.

chiefly of material washed by the river from the Boylston plain, followed the retreating ice margin.

To the eastward, between the former site of South Clinton station and the South Dike outlet, east and south of the Nashua River, this plain is very fragmentary, much complicated by the eskers of the Boylston stage,[1] and attains its normal elevation for only a small fraction of the area. But west of the river this earliest section of the Clinton plain has its principal and most interesting development. Southward it terminates in the remarkably abrupt and perfect erosion scarp, more than a mile in length and 70 to 80 feet high, overlooking

[1] TECHNOLOGY QUARTERLY, 12, 315.

the river, and northward it presents a very normal ice-contact slope bordering Cunningham Brook for practically its entire length, while to the eastward it ends in a quite well-characterized free frontal slope, and westward it abuts against the higher and older marginal plain. It is thus highly differentiated in its margins, and that it is merely a remnant, the head of a plain once continuous across the modern valley of the river, is obvious. This delta remnant, more than a mile in length, varies in breadth from about 1,000 feet in the eastern half to fully 3,000 feet in the western half, but especially in this broad western portion it is much diversified and subdivided by kettles, the two largest,

FIG. 2.—VIEW ON THE NORTH DIKE PLAIN, LOOKING EAST ACROSS SANDY POND TOWARD THE SOUTH DIKE OUTLET.

one east and one west of the old road from Clinton to Boylston, being indicated on the map. This southernmost original section or member of the Clinton plains, now so widely and deeply divided by the Nashua River, may conveniently be designated the *Nashua plain.*

The valley of Cunningham Brook is throughout virtually a foss between the normally steep and irregular ice-contact margin, just described, on the south, and a normally gentle and lobate frontal slope on the north. Ascending this frontal slope we find ourselves on the extensive section of the Clinton plain traversed from end to end by the North Dike and crossed transversely by the group of rock ridges, on one of which was formerly the Catholic cemetery. This North

Dike plain is the largest and, geologically, the most important of the Clinton plains, made doubly important to the student of glacial geology by the great extent to which it has been dissected by boring and excavation. Its length is measured by the North Dike, and, like that, it abuts at either end against a prominent drumloid. It is not only crossed midway of its length by narrow ridges of contorted schist, but it is nearly divided in the eastern half by a prominent line of kettles, the largest of which holds Sandy Pond. Still farther east, between Sandy Pond and the Nashua River and in the lee of Burdette Hill, the plain becomes very fragmentary, and is finally reduced

FIG. 3.—VIEW ON THE NORTH DIKE PLAIN, LOOKING WEST TOWARD THE PROMINENT DRUMLOID AGAINST WHICH THE NORTH DIKE TERMINATES.

to a maze of interlacing kames inclosing numerous kettles and irregular hollows. Figure 1 is a somewhat distant view of this area looking northeasterly across the great bend of the Nashua, where the river finally turns to the northward parallel with the main axis of the valley. The North Dike plain, steadily gaining in height northward, terminates in that direction in a very typical ice-contact slope, diversified by kettles and following closely the southern border of Coachlace Pond. The limits here defined give the North Dike plain an extreme length, east-west, of a little over two miles, and a maximum breadth between the ice-contact and frontal slopes of about a mile. Figures 2, 3, and 4 are general views across the North Dike plain before the construction of the dike.

Coachlace Pond, like Cunningham Brook, occupies a foss between successive segments of the Clinton delta. The plains north of the pond, although almost ideal in development, are much less extensive than the North Dike and Nashua plains, and, unlike the southern plains, do not span the entire breadth of the valley.

First in order comes the Mossy Pond plain in the southeastern angle of the Boston and Maine and the New York, New Haven and Hartford Railroads. It is divided nearly transversely by the northern lobe of Coachlace Pond, known as Mossy Pond — as the North Dike plain is divided by Sandy Pond and contiguous kettles. Notwithstanding its divided form, and this is clearly an original feature due to kettle hole development, this is a beautifully perfect and normal plain, terminating southward in a gentle frontal slope, and northward, for part of its length, in a broken ice contact, and partially surrounding a small drumlin on its northwestern border. This plain is almost or virtually continuous across the New Haven Railroad, with the singularly perfect square plain nearly three-fourths of a mile in diameter in the northeastern angle of the two railroads, mainly in Clinton and partly in Lancaster, and admirably expressed on the topographic map. This plain — *Lancaster plain*, as we may call it — presents ice-contact slopes to the north and east, but the frontal slope, as noted, merges to the

FIG. 4. — BURDETTE HILL, LOOKING NORTHEAST FROM THE NORTH DIKE, AND SHOWING THE STRAIGHT AND SHARPLY DEFINED CONTACT OF THE PLAIN AND THE HILL.

west with the ice contact of the Mossy Pond plain, and the foss is only partially developed.

No trace of the Clinton delta has been observed north of this fourth segment, and it is interesting to find its last expression so ideal in development. We cannot escape the conclusion that north of the Lancaster plain the retreat of the ice margin was too continuous and rapid to permit the development of mature delta plains in the increasingly greater depths of Lake Nashua; but it is equally certain that up to this latitude the recession was intermittent, with three and probably four halts of sufficient length to allow the glacial streams to extend their united deltas across the basin, the maximum development being thus approximately realized for all but the Mossy Pond delta. It thus appears that with each halt of the ice margin the lake basin, due to recession of the ice, was nearly or quite obliterated by the encroachment of its own deposits.

The lines of halting cannot be correlated with the prelacustrine topography, and were clearly not determined by the configuration of the valley; but it is significant that throughout — and more and more with increasing latitude — the ice continued to occupy the eastern side of the valley after the western side was free, with, however, conditions favorable to the development of a nearly continuous line of kettles and basins across the successive deltas along the most probable course of the buried gorge of the Nashua River.[1]

The extreme range in latitude of the Clinton plains is nearly four miles, but the shore of this stage of Lake Nashua can be identified at some points where no important deposit was made. Thus, Walnut Street in the village of Clinton, on which is the office of the Metropolitan Water Works, occupies a natural terrace on the western slope of the Cedar Hill drumloid which agrees in elevation with the Clinton plains and is clearly a beach of Lake Nashua formed after the ice margin had receded from the latitude of Clinton, or during the latter part of the Clinton stage. No attempt has been made to trace this shore farther north, but it should be possible, apparently, to identify it at least as far north as Harvard. It is obvious, however, that this record of the glacial lake must become less distinct northward, as the time available for its inscription was more brief.

Tributary Eskers. — The double line of eskers in the vicinity of

[1] Technology Quarterly, 12, 293–300.

South Clinton station has been referred to the Boylston stage,[1] and the knob of coarse gravel rising from the Nashua plain midway of the length of its northern erosion scarp is best regarded as a buried remnant of still another esker of the Boylston stage. The only well-characterized esker to be safely correlated with the Clinton stage or regarded as tributary to the Clinton plains is the very normal example closely bordering the west bank of the Nashua River for one-fourth of a mile immediately south of the Wachusett Dam, and probably continued in the double line of esker south of the great bend of the

FIG. 5. — VIEW LOOKING SOUTH FROM THE WESTERN END OF THE WACHUSETT DAM, SHOWING THE ESKER BORDERING THE NASHUA RIVER, AND ON THE RIGHT THE TUMULTUOUS EASTERN END OF THE NORTH DIKE PLAIN.

river. At the northern end this esker agrees closely in height with, and is covered by or lost in, a fragment or outlier of the North Dike plain lying against the southeastern base of Burdette Hill. The view southward from this point (Figure 5) shows the esker in its relations to the river and to the tumultuous portion of the North Dike plain previously described. This view is almost the reverse of that in Figure 1.

In this connection, also, may be mentioned the wavering line of eskers on the east side of the Nashua Valley, between Ban Hill Pond and Lancaster Commons. These have been correlated with the Bolton

[1] TECHNOLOGY QUARTERLY, 12, 315.

station outlet of the Clinton stage and the adjacent marginal and apron plains.[1]

Marginal Slopes. — As previously explained, the marginal slopes of the Clinton plains include normal examples of original ice-contact and frontal slopes and secondary erosion slopes. Both types of original slopes are more or less perfectly developed on each one of the four successive members of the Clinton series, and are combined to form a typical foss between the North Dike and Nashua plains. (Figure 6.) To the westward this foss, which is the valley but not the product of

FIG. 6. — VIEW LOOKING UP THE FOSS VALLEY OF CUNNINGHAM BROOK, WITH THE ICE-CONTACT SLOPE OF THE NASHUA PLAIN ON THE LEFT, AND THE FRONTAL SLOPE OF THE NORTH DIKE PLAIN ON THE RIGHT.

Cunningham Brook, expands, through the failure of the North Dike plain to attain in this direction the possible maximum area, into a broad meadow comparable in its geological relations to the basin of Coachlace Pond. Eastward, also, Cunningham Brook, before joining the Nashua, flows through a broad and deep basin floored in part by granite ledges and bowlder clay, but clearly due in this instance, as indicated by the steep slopes to the north and west, to the burial and subsequent melting of a block of ice.

[1] TECHNOLOGY QUARTERLY, 12, 321.

Erosion slopes find their only striking development in the plains of the Clinton series, in the valley from 2,000 to 3,000 feet wide which the Nashua River has cut through the Nashua plain east of Boylston. These erosion scarps (Figure 7) are ideal in their steepness, height, absolute definition above and below, and in their splendid concave curves and salient cusps, with abandoned channels of the river at the base or meandering across the flood plain.

What it was that first determined the course of the Nashua across

FIG. 7.— EROSION SLOPE OF THE NASHUA PLAIN ON THE SOUTH SIDE OF THE NASHUA RIVER EAST OF BOYLSTON.

the plain below Boylston to the eastward instead of the northeastward along the line of great kettles we can only conjecture, but a foss similar to that occupied by Cunningham Brook is, perhaps, the most probable suggestion; and we may readily believe that a controlling factor was the fact that all the Clinton plains either become very fragmentary or die out altogether toward the east side of the valley. In other words, on the final withdrawal of the waters of Lake Nashua by the opening of the outlet at Ayer, the river simply took the most direct course to an open channel at a low level, and the linear series

of kettles, described in the next section, evidently lacked the continuity necessary to determine the choice of that line.

Kettles. — Kettles, or depressions due to the melting of buried or partially buried masses of ice, are a feature of nearly all the ice-contact margins, and their entirely normal relations make them of rather less interest than the series of large, longitudinal kettles and basins previously referred to as more or less completely dividing in a north-south direction all but the Lancaster plain. This series is most strikingly developed in Mossy Pond, the southern lobe of Coachlace Pond, and Sandy Pond (Figure 8), and from Sandy Pond a practically continuous

FIG. 8. — SANDY POND FROM THE NORTHEAST, AS IT APPEARED BEFORE THE DEFORESTING OF THE NORTH DIKE PLAIN.

line of large kettles (Figure 9) extends southwesterly to Cunningham Brook. Three of these kettles are deep enough to hold permanent kettle ponds. Across the northern section of the Nashua plain to its bold erosion scarp the principal development of kettles bears still more to the southwest and is, perhaps, less continuous, although it includes one large and deep example, which is greatly elongated in the direction of the series, and also finds expression in the 370-foot contour on the map.

The continuity and directness of this line to Cunningham Brook is clearly shown on the map, which also brings out clearly the fact, previously noted, that these depressions coincide approximately or exactly

with the most probable course of the buried gorge of the Nashua River. This relation has been very fully demonstrated for the territory south of the Boston and Maine Railroad by numerous deep borings, and its recognition raises one of the most interesting questions presented by the study of kettles; that is, the mode and conditions of their formation. The usual conception of a kettle presupposes a residuary block of ice, isolated by melting (or possibly by floating, as in the case of a stranded berg), resting on rock or ground moraine, covered by modified drift, and subsequently melted. But here we have kettles of very typical forms and widely varying sizes which are not floored or under-

FIG. 9. — KETTLE HOLE IN THE NORTH DIKE PLAIN SOUTHWEST OF SANDY POND, WITH THE CEMETERY RIDGE IN THE BACKGROUND.

lain by rock or till, but by sand and gravel 100 feet or more in thickness. This fact, together with the complete absence of till from the section, makes it, apparently, impossible to attribute these kettles to the burial and melting of truly residuary fragments of the ice sheet. The further discussion of this question may best be reserved, however, for a later section on the structures of the deltas.

The basin of Sandy Pond is the largest and deepest of all the kettles. The map and Figure 8 clearly exhibit its features above its normal water level (334 feet). The maximum depth, before the level was lowered during the construction of the North Dike, was 66 feet,

the elevation of the bottom being 268 feet. It is interesting to note that the normal water level of Sandy Pond was nearly 55 feet above that of the Nashua River only a little more than a quarter of a mile to the southeast, and the strip of the North Dike plain separating the basin of the pond from the still larger basin in which the foss valley of Cunningham Brook terminates is so narrow, being hardly wider than a normal esker, as to permit a strong outward flow of the water from Sandy Pond. This leakage gave rise to a brook which, although only a quarter of a mile long, often exceeded Cunningham Brook in the volume of water delivered to the river.

(*To be continued.*)

THE METALLURGY OF LEAD.[1]

By H. O. HOFMAN.

In the last twenty years of the nineteenth century the lead-smelting industry underwent important changes. Most of these were the result of new conditions arising in the United States, where the treatment of the ores is carried out, not in small works near the mines, but in large, centrally-situated smelting plants, to which the ores are shipped from various mining regions. As the competition is considerable all the details of work have been greatly improved, the cost reduced, and the yield increased. Lead ores are smelted in the reverberatory furnace, the ore hearth, and the blast furnace. The use of the first two is restricted, as they are suited only for galena ores (the more common), or mixtures of galena and carbonate, which contain not less than 58 per cent. of lead and not more than 4 per cent. of silica; further, ores to be treated in the ore hearth should run low in or be free from silver, as the loss in the fumes is excessive. In the blast furnace all lead ores are successfully smelted. Blast-furnace treatment has, therefore, become more general than any other.

To the two methods of working in the reverberatory furnace, represented by the English and Carinthian furnaces (described in *Encyclopædia Britannica*, Vol. XIV, p. 375), a third, the Silesian, must be added. While by the former processes as much lead as possible is extracted in the furnace, with the Silesian method a very low temperature is used, thus taking out about one-half of the lead and leaving very rich slags (50 per cent. lead) to be smelted in the blast furnace, the ultimate result being a very much higher yield than by either of the other processes. The Silesian furnace has an oblong hearth, 16 feet by 8 feet 10 inches, sloping from the fire bridge to the flue bridge. This causes the lead to collect at the coolest part of the hearth,

[1] Reprinted, by permission of the publishers, from the article on Lead, by Prof. H. O. Hofman, in the new volumes of the *Encyclopædia Britannica*, copyright 1902, by the Encyclopædia Britannica Company.

whence it is tapped, etc., as in the English furnace. A charge of 6,180 pounds of galena ore (70 per cent. lead) is worked in twelve hours by three men, 0.46 ton of coal being consumed per ton of ore charged. The loss in lead by the combined reverberatory and blast-furnace treatment is only 3.2 per cent.

In the hearth process the blocks of cast iron forming the sides and back of the Scottish furnace (see *Encyclopædia Britannica*, Vol. XIV, p. 375) are now generally replaced in the United States by water-cooled shells (water jackets) of cast iron. In this way continuous working has been rendered possible, whereas formerly operations had to be stopped every twelve or fifteen hours to allow the over-heated blocks and furnace to cool down. The latest improvement (which somewhat changes the mode of working) is that by Moffett. While he also prevents interruption of the operation by means of water jackets, he uses hot blast, and produces, besides metallic lead, large volumes of lead fumes, which are drawn off by fans through long cooling tubes, and then forced through suspended bags which filter off the dust, called blue powder. This, a mixture of lead sulphate (45 per cent.) and oxide (44 per cent.), with some sulphide (8 per cent.), zinc, and carbonaceous matter, is agglomerated by a heap-roast, and then smelted in a slag-eye furnace with gray slag from the ore hearth. The furnace has, however, in addition to the usual tuyères near the bottom, a second set near the throat, in order to effect a complete oxidation of all combustible matter. Much fume is thus produced. This is drawn off, cooled, and filtered, and forms a white paint of good body, consisting of about 65 per cent. lead sulphate, 26 per cent. lead oxide, 6 per cent. zinc oxide, and 3 per cent. other substance. Thus, in the Moffett method, it is no matter whether metal or fume is produced, as in either case it is saved and the price is about the same.

In smelting at once in the same blast furnace ores of different character, the old use of separate processes of precipitation, roasting and reduction, and general reduction prevailing in the Harz Mountains (see *Encyclopædia Britannica*, Vol. XIV, p. 376), Freiberg, and other places, to suit local conditions, has had to be abandoned. Ores are smelted raw if the fall of matte (metallic sulphide) does not exceed 5 per cent.; otherwise they are subjected to a preliminary oxidizing roast to expel the sulphur, unless they run too high in silver, say 100 ounces to the ton, when they are smelted raw. The leading reverber-

atory furnace for roasting lead-bearing sulphide ores has a level hearth 14–16 feet wide and 60–80 feet long. It puts through 9–12 tons of ore in twenty-four hours, reducing the percentage of sulphur to 2–4 per cent., and requires four to six men and about two tons of coal. In many instances it has been replaced by mechanical furnaces, which are now very common in roasting sulphide copper ores. (See Acid and Alkali Manufacture.) A modern blast furnace is oblong in horizontal section, and about 24 feet high from furnace floor to feed floor. The shaft, resting upon arches supported by four cast-iron columns about 9 feet high, is usually of brick—red brick on the outside, fire brick on the inside; sometimes it is made of wrought-iron water jackets. The smelting zone always has a bosh and a contracted tuyère section. It is enclosed by water jackets, which are usually cast iron, sometimes mild steel. The hearth always has an Arents siphon tap. This is an inclined channel running through the side-wall, beginning near the bottom of the crucible and ending at the top of the hearth, where it is enlarged into a basin. The crucible and the channel form the two limbs of an inverted siphon. While the furnace is running, the crucible and channel remain filled with lead; all the lead reduced to the metallic state in smelting collects in the crucible, and rising in the channel overflows into the basin, whence it is removed. The slag and matte formed float upon the lead in the crucible and are tapped, usually together, at intervals into slag-pots, where the heavy matte settles on the bottom and the light slag on the top. When cold they are readily separated by a blow from a hammer. The following table gives the dimensions of some well-known American lead furnaces:

Locality.	Lead Blast-Furnace.		Height Tuyère to Throat.
	Year.	Tuyère Section.	
		Inches.	Feet.
Leadville, Colorado	1880	33 x 84	14
Denver, "	1880	36 x 100	17
Durango, "	1882	36 x 96	12.6
Denver, "	1892	42 x 100	16
Leadville, "	1892	42 x 120	18
Salt Lake City, Utah	1895	45 x 140	20

A furnace 42 by 120 inches at the tuyères, with a working height of 17–20 feet, with twelve men, using 12 per cent. of coke and two-pound blast pressure, will put through in twenty-four hours 85–100 tons average charge, *i.e.*, one that is medium coarse, which contains 12–15 per cent. lead, not over 5 per cent. zinc, and makes under 5 per cent. matte. In making up a charge the ores and fluxes whose chemical compositions have been determined are mixed so as to form typical slags out of the components not to be reduced to the metallic or sulphide state (silicates of ferrous and calcic oxides, incidentally of aluminium oxide, which have been found to do successful work). Such slags contain SiO_2 30–33 per cent., Fe(Mn)O 27–50 per cent., Ca(Mg, Ba)O 12–28 per cent., and retain less than 1 per cent. lead and 1 ounce silver to the ton. The leading products of the blast furnace are argentiferous lead (base bullion), matte, slag, and flue dust (fine particles of charge and volatilized metal carried out of the furnace by the ascending gas current). The base bullion (assaying 300 ± ounces per ton) is desilverized (see below); the matte (Pb 8–12 per cent., Cu 3–4 per cent., Ag $\frac{1}{3}$–$\frac{1}{5}$ of the assay value of the base bullion, rest Fe and S) is roasted and resmelted, when part of the argentiferous lead is recovered as base bullion, while the rest remains with the copper, which becomes concentrated in a copper matte (60 per cent. copper), to be worked up by separate processes (see Copper). The slag is a waste product, and the flue dust, collected by spécial devises in dust chambers, is briquetted by machinery, with lime as a bond, and then resmelted with the ore charge. The yield in lead is over 90 per cent., in silver over 97 per cent., and in gold 100 per cent. The cost of smelting a ton of ore in Colorado in a single furnace 42 by 120 inches at the tuyères is about three dollars.

Refining. — The lead produced in the reverberatory furnace and the ore hearth is of a higher grade than that produced in the blast furnace, as the ores treated are purer and richer, and the reducing action is less powerful. The following analysis of blast furnace lead of Freiberg, Saxony, is from an exceptionally impure lead: Pb 95.088, Ag 0.470, Bi 0.019, Cu 0.225, As 1.826, Sb 0.958, Sn 1.354, Fe 0.007, Zn 0.002, S 0.051. Of the impurities most of the copper, nickel and copper, considerable arsenic, some antimony, and small amounts of silver, are removed by liquation. The lead is melted down slowly, when the impurities separate in the form of a scum (dross) which is easily

removed. The purification by liquation is assisted by poling the lead when it is below redness. A stick of green wood is forced into it, and the vapors and gases set free stir it up and expose new surfaces to the air, which at this temperature has only a mildly oxidizing effect. The pole, the use of which is awkward, has been replaced by dry steam, which has a similar effect. In order to remove tin, arsenic, and antimony, the lead has to be brought up to a bright red heat, when the air has a strongly oxidizing effect. Tin is removed mainly as a powdery mixture of stannate of lead and lead oxide; arsenic and antimony, as a slagged mixture of lead oxide and arsenate and antimonate of lead. They are readily withdrawn from the surface of the lead and are worked up into antimony (arsenic), tin-lead, and antimony-lead alloys. Liquation, if not followed by poling, is carried on as a rule in a reverberatory furnace with an oblong, slightly trough-shaped inclined hearth; if the lead is to be poled it is usually melted down in a cast-iron kettle. If the lead is to be liquated and then brought to a bright red heat, both operations, for convenience' sake, are carried on in the same reverberatory furnace. This has an oblong, dish-shaped hearth of acid or basic fire brick built into a wrought-iron pan, which rests on transverse rails supported by longitudinal walls. The lead is melted down at a low temperature and drossed. The temperature is then raised, and the scum which forms on the surface is withdrawn until pure litharge forms, which only takes place after all the tin, arsenic, and antimony have been eliminated.

Desilverizing. — Silver is extracted from lead by means of the process of cupellation (see *Encyclopædia Britannica*, Vol. XIV, p. 376). Formerly all argentiferous lead had to be cupelled, and the resulting litharge then reduced to metallic lead. In 1833 Pattinson invented his process (*ibid.*, p. 377) by means of which practically all the silver is concentrated in 13 per cent. of the original lead to be cupelled, while the rest becomes market lead. In 1842 Karsten (*loc. cit.*) discovered that lead could be desilverized by means of zinc. His invention, however, only took practical form in 1850–2, through the researches of Parkes, who showed how the zinc-silver-lead alloy formed could be worked and the desilverized lead freed from the zinc it had taken up. In the Parkes process only 5 per cent. of the original lead need be cupelled. Thus, while cupellation still furnishes the only means for the final separation of lead and silver, it has become an auxiliary process to the two methods of concentration given. Of these the Pattin-

son process has become subordinate to the Parkes process, as it is more expensive and leaves more silver and impurities in the market lead. It holds its own, however, when base bullion contains bismuth in appreciable amounts, as in the Pattinson process bismuth follows the lead to be cupelled, while in the Parkes process it remains with the desilverized lead which goes to market, and lead of commerce should contain little bismuth. At Freiberg, Saxony, the two processes have been combined. The base bullion is imperfectly Pattinsonized, giving lead rich in silver and bismuth, which is cupelled, and lead low in silver, and especially so in bismuth, which is further desilverized by the Parkes process.

The effect of the two processes on the purity of the market lead is clearly shown by the two following analyses by Hampe, which represent lead from Lautenthal, in the Harz Mountains, where the Parkes process replaced that of Pattinson, the ores and smelting process remaining practically the same:

Process.	Pb.	Cu.	Sb.	As.	Bi.	Ag.	Fe.	Zn.	Ni.
Pattinson	99.966200	0.015000	0.010000	none	0.000600	0.002200	0.004000	0.001000	0.001000
Parkes	99.983139	0.001413	0.005698	none	0.005487	0.000460	0.002289	0.000834	0.000680

Cupelling. — The reverberatory furnace commonly used for cupelling goes by the name of the English cupelling furnace. It is oblong, and has a fixed roof and a movable iron hearth (test). Formerly the test was lined with bone ash; at present the hearth material is a mixture of crushed limestone and clay (3 : 1), or Portland cement, either alone or mixed with crushed fire brick; in a few instances the lining has been made of burnt magnesite. In the beginning of the operation enough argentiferous lead is charged to fill the cavity of the test. After it has been melted down and brought to a red heat, the blast, admitted at the back, oxidizes the lead and drives the litharge formed towards the front, where it is run off. At the same time small bars of argentiferous lead, inserted at the back, are slowly pushed forward, so that in melting down they may replace the oxidized lead. Thus the level of the lead is kept approximately constant, and the silver becomes concentrated in the lead. In large works the silver-lead alloy is removed when it contains 60–80 per cent. silver, and the cupella-

tion of the rich bullion from several concentration furnaces is finished in a second furnace. At the same time the silver is brought to the required degree of fineness, usually by the use of nitre. In small works the cupellation is finished in one furnace, and the resulting low-grade silver fined in a plumbago crucible, either by overheating in the presence of air, or by the addition of silver sulphate to the melted silver, when air or sulphur trioxide and oxygen oxidize the impurities. The lead charged contains about 1.5 per cent. of silver if it comes from a Pattinson plant, from 5–10 per cent. if from a Parkes plant. In a test 7 feet by 4 feet 10 inches, and 4 inches deep, about 6 tons of lead are cupelled in twenty-four hours. A furnace is served by three men, working in eight-hour shifts, and requires about two tons of coal, which corresponds to about 110 gallons reduced oil, air being used as atomizer. The loss in lead is about 5 per cent. The latest cupelling furnaces have the general form of a reverberatory copper-smelting furnace. The working door through which the litharge is run off lies under the flue which carries off the products of combustion and the lead fumes; the lead is charged and the blast is admitted near the fire bridge.

Pattinson Process. — In the Pattinson process the argentiferous lead is melted down in the central cast-iron kettle of a series of 8–15, placed one next to the other, each having a capacity of 9–15 tons and a separate fireplace. The crystals of impoverished lead which fall to the bottom upon coaling the charge are taken out with a skimmer and discharged into the neighboring kettle (say to the right) until about two-thirds of the original charge has been removed, then the liquid, enriched lead is ladled into the kettle on the opposite side. To the kettle, two-thirds full of crystals of lead, is now added lead of the same tenor in silver, the whole is liquidified, and the cooling, crystallizing, skimming, and ladling are repeated. The same is done with the kettle one-third filled with liquid lead, and so on until the first kettle contains market lead, the last cupelling lead. The intervening kettles contain leads with silver contents ranging from above market to below cupelling lead. The original Pattinson process has been in many cases replaced by the Luce-Rozan process (1870), which does away with arduous labor and attains a more satisfactory crystallization. The plant consists of two tilting oval metal pans (capacity 7 tons), one cylindrical crystalling pot (capacity 22 tons), with two discharging spouts, and one steam-inlet opening, two lead molds (capacity

$3\frac{1}{2}$ tons), and a steam crane. Pans and pot are heated from separate fireplaces. Supposing the pot to be filled with melted lead to be treated, the fire is withdrawn beneath and steam introduced. This cools and stirs the lead, when crystals begin to form. As soon as two-thirds of the lead has separated out in the form of crystals the steam is shut off and the liquid lead drained off through the two spouts into the molds. The fire underneath the pot is again started, the crystals are liquidified, and one of the two pans, filled with melted lead, is tilted by means of the crane and its contents poured into the pot. In the meantime the lead in the molds, which has solidified, is removed with the crane and stacked to one side until its turn comes to be raised and charged into one of the pans. The crystallization proper lasts one hour, the working of a charge four hours, six charges being run in twenty-four hours.

Parkes Process.—It is absolutely necessary for the success of the Parkes process that the zinc and lead should contain only a small amount of impurity. The spelter used must, therefore, be of a good grade, and the lead is usually first refined in a reverberatory furnace (the softening furnace) as described above. The capacity of the furnace must be 10 per cent. greater than that of the kettle into which the softened lead is tapped, as the dross and skimmings formed amount to about 10 per cent. of the weight of the lead charged. The kettle is spherical, and is suspended over a fireplace by a broad rim resting on a wall; it is usually of cast iron. Most kettles at present hold 30 tons of lead; some, however, have double that capacity, When zinc is placed on the lead (heated to above the melting point of zinc), liquidified, and brought into intimate contact with the lead by stirring, then gold, copper, silver, and lead will combine with the zinc in the order given. By beginning with only a small amount of zinc all the gold and copper, and some silver and lead, will be alloyed with the zinc to a so-called gold or copper crust, and the residual lead will be saturated with zinc. By removing from the surface of the lead this first crust and working it up separately (liquating, retorting, and cupelling), doré silver is obtained. By the second addition of zinc most of the silver will be collected in a saturated zinc-silver-lead crust, which, when worked up, gives fine silver. A third addition becomes necessary to remove the rest of the silver when the lead will assay only 0.1 ounce silver per ton. As this complete desilverization is only possible by the use of an excess of zinc, the unsaturated zinc-silver-lead alloy is

put aside to form part of the second zincing of the next following charge. In skimming the crust from the surface of the lead some unalloyed lead is also drawn off and has to be separated by an additional operation (liquation); as, running lower in silver than the crust, it would otherwise reduce its silver content and increase the amount of lead to be cupelled. A zincing takes 5–6 hours; 1.5–2.5 per cent. of zinc is required for desilverizing. The liquated zinc-silver-lead crust contains 5–10 per cent. of silver, 30–40 per cent. zinc, and 65–50 per cent. lead. Before it can be cupelled it has to be freed from most of the zinc, which is accomplished by distilling in a retort made of a mixture similar to that of the plumbago crucible. The retort is pear-shaped, and holds 1,000–1,500 pounds of charge, consisting of liquated crust mixed with 1–3 per cent. of charcoal. The condenser commonly used is an old retort. The distillation of 1,000 pounds charge lasts 5–6 hours, requires 500–600 pounds of coke, or 30 ± gallons of reduced oil, and yields about 10 per cent. metallic zinc, and 1 per cent. blue powder, a mixture of finely divided metallic zinc and zinc oxide. About 60 per cent. of the zinc used in desilverizing is recovered in a form to be used again. One man serves 2–4 retorts. The desilverized lead, which retains 0.6–0.7 per cent. of zinc, has to be refined before it is suited for industrial use. The operation is carried on in a reverberatory furnace or in a kettle. In the reverberatory furnace, similar to the one used in softening, the lead is brought to a bright red heat and air allowed to have free access. The zinc and some lead are oxidized; part of the zinc passes off with the fumes, part is dissolved by the litharge, forming a melted mixture which is skimmed off and reduced in a blast furnace or a reverberatory smelting furnace. In the kettle covered with a hood the zinc is oxidized by means of dry steam, and incidentally some lead by the air which cannot be completely excluded. A yellowish powdery mixture of zinc and lead oxides collects on the lead; it is skimmed off and sold as paint. From the reverberatory furnace or the kettle the refined lead is siphoned off into a storage (market) kettle after it has cooled somewhat, and from this it is siphoned off into molds placed in a semicircle on the floor. In the process the yield in metal, based upon the charge in the kettle, is lead, 99 per cent.; silver, 100+ per cent.; gold, 98–100 per cent. The plus silver is due to the fact that in assaying the base bullion by cupellation the silver lost by volatilization and cupel absorption is neglected. In the

United States the cost of desilverizing a ton of base bullion is about six dollars.

Statistics. The world's production of lead in 1899 was, according to *The Mineral Industry* (1900, p. 431), 803,273 metric tons, viz.: Austria, 9,736; Belgium, 15,700; Canada, 9,917; Chile, 171; France, 15,981; Germany, 129,225; Greece, 19,059; Hungary, 2,166; Italy, 20,543; Japan, 1,989; Mexico, 84,656; New South Wales, 70,000; Russia, 250; Spain, 184,007; Sweden, 1,606; United Kingdom, 41,500; United States, 196,938.

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THE METALLURGY OF SILVER.[1]

By H. O. HOFMAN.

From the metallurgical point of view silver ores may be classified as real silver ores and argentiferous ores. The former consist of silver minerals and gangue (vein matter, country rock). The leading silver minerals are native silver, Ag; cerargyrite, AgCl; argentite, Ag_2S; proustite, $3Ag_2S + As_2S_3$; pyrargyrite, $3Ag_2S + Sb_2S_3$; polybasite, $9Ag_2S + As_2S_3$, and stephanite, $5Ag_2S + Sb_2S_3$. The silver is commonly recovered by milling, *i.e.*, amalgamation or lixiviation. Argentiferous ores consist of silver-bearing base metal minerals and gangue. Lead and copper ores, carrying silver in some form or other, are the leading representatives. The silver is extracted from the gangue with the base metal, usually by smelting, and the two are then separated by special processes (see Lead, Copper). Milling is cheaper than smelting, but the yield in silver is lower. Often it is more profitable to smelt real silver ores with argentiferous ores than to mill them, the greater cost being more than balanced by the increased yield. Milling is practised mainly in isolated localities near the mine producing the ore. As any given region is opened up by railways, cheapening transportation, milling is apt to give way to smelting. Thus, on the American continent, which produces the bulk of the world's silver, milling is still prominent in South America and Mexico, while in the United States it has, to a considerable extent, been replaced by smelting.

Amalgamation is based on the property of quicksilver to extract the silver from finely pulverized ore and collect it in the form of an amalgam. When the rock has been separated from the amalgam by a washing operation, the quicksilver is recovered by distillation in an iron retort, and the remaining crude retort silver melted into bars and shipped to a refinery, which removes the impurities, the leading one of

[1] Reprinted, by permission of the publishers, from the article on Silver, by Prof. H. O. Hofman, in the new volumes of the *Encyclopædia Britannica*, copyright 1902, by the Encyclopædia Britannica Company.

which is copper. A silver ore is either free milling or refractory; that is, the silver mineral is readily amalgamated or it is not. In free-milling ore the silver is present either in the native state, or as chloride, or as simple sulphide. Complex silver minerals (sulph-arsenides and antimonides) which are difficult to amalgamate must be made amenable to quicksilver, and the simplest way of doing this is to convert the silver into chloride. This is imperfectly accomplished, in the wet way, by cupric and cuprous chloride solutions, but completely so, in the dry way, by roasting with salt (chlorodizing roasting). According as a preliminary chlorodizing roast has or has not been given, the process is classed as roast amalgamation or raw amalgamation. The leading raw amalgamation processes are the Patio and the Washoe; then follow the Cazo, Fondon, and Kröhnke. Of the roast amalgamation processes the European Barrel or Freiberg, the Reese River, and the Francke-Tina are the most important.

The *Patio* process (for an outline of which see *Encyclopædia Britannica*, Vol. XXII, p. 70) is carried out principally in Mexico. It aims at amalgamating the silver in the open in a circular enclosure, the floor of which is generally built of flagstones. In order to facilitate the decomposition of the silver mineral, salt and magistral are worked into the wet pulp, spread out on the floor. Magistral is cupriferous pyrites roasted to convert the copper into soluble sulphate, which is the active agent. The amalgamation proceeds very slowly, as the sole extraneous heat is that of the sun. According to Laur, at Guanaxuato, Mexico, 92.77 per cent. of the total silver recovered was extracted after 12 days, 97.55 per cent. after 25 days, 99.70 per cent. after 28 days, and 100 per cent. after 33 days. The loss of quicksilver in the process is large, owing to the formation of calomel, which is not saved. The yield in silver is low, unless the ores are exceptionally free milling; the bullion produced is high grade, as refractory silver minerals are hardly attacked. The process is suited to easy ores and a region where the climate is warm and dry, and horse or mule power, labor, and quicksilver are cheaper than fuel and water.

The *Washoe* process is the leading raw amalgamation process of the United States, where it was invented, in 1859, by A. B. Paul. It consists in wet-stamping coarsely crushed ore, settling the sands and slimes produced, and grinding and amalgamating them in steam-heated iron pans with or without the use of chemicals (salt and blue vitriol). The ores may contain a larger proportion of sulphurets and complex

silver minerals than with the Patio process and still give a satisfactory extraction. They are crushed to egg size in a rock breaker, and pulverized to pass a 40-mesh sieve in a California stamp mill, which treats in 24 hours about 3 tons per stamp. A 10-stamp mill is fed by one rock breaker, and discharges the liquid pulp into 10–15 wooden settling tanks 9 x 5 x 8 feet, the settled contents of which are shovelled out and charged into the pans. The pan in general use is the combination pan. It has a flat, cast-iron bottom, 5 feet in diameter, and wooden sides about 30 inches high, the lower parts of which are lined with cast iron. In the center is a hollow cone, through which passes the driving shaft, geared from below. This turns the grinding apparatus (driver with muller), which can be raised and lowered. The speed is 60–90 revolutions per minute. To the bottom and muller are attached grinding plates (shoes and dies), which are replaced when worn, and to the sides three wings, to deflect the moving pulp towards the centre and thus establish the necessary pulp current. The lower side of the bottom has also a steam chest. A 10-stamp mill has 4–6 pans, which receive 2-ton charges. In working, the muller is raised half an inch, the pan charged with water and then with ore, the muller is lowered, salt and blue vitriol are added, and the charge is ground for 3–4 hours. The pulp is heated with live steam to about 90° C., and kept at that temperature by exhaust steam in the bottom chest. After grinding, the muller is raised and quicksilver added, and the silver then amalgamated in 3–4 hours. In amalgamating without the use of chemicals finely divided iron, worn from the shoes and dies in the stamp mill and the pan, decomposes cerargyrite and argentite, and the liberated silver is taken up by the quicksilver; the process is hastened by adding salt. When salt and blue vitriol are added to the charge they form sodium sulphate and cupric chloride ($2NaCl + CuSO_4 = Na_2SO_4 + CuCl_2$), both of which are readily soluble in water. Cupric chloride acts upon argentite ($Ag_2S + CuCl_2 = 2AgCl + CuS$), proustite ($4Ag_3AsS_3 + 12CuCl_2 = 8AgCl, 2Ag_2S, 2CuS, As_2S_3, 5S$), pyrargyrite ($2Ag_3SbS_3 + 4CuCl_2 = 6AgCl + 2CuS + Sb_2S_3 + S$), and is also reduced to cuprous chloride by metallic iron ($2CuCl_2 + Fe = Cu_2Cl_2 + FeCl_2$). This salt, insoluble in water but soluble in brine, also acts upon argentite ($Ag_2S + Cu_2Cl_2 = 2AgCl + CuS + Cu$) and pyrargyrite ($2Ag_3SbS_3 + Cu_2Cl_2 = AgCl + Ag_2S + 2Ag + 2CuS + Sb_2S_3$) and would give, with silver sulphide in the presence of quicksilver, the Patio reaction — metallic silver, cupric sulphide, and mercu-

rous chloride ($2Ag_2S + Cu_2Cl_2 + Hg = 4Ag + 2CuS + Hg_2Cl_2$), but the iron decomposes the quicksilver salt ($Hg_2Cl_2 + Fe = Hg_2 + FeCl_2$) setting free the quicksilver. The amalgamation is rapid. Thus Austin found that at the Charleston mills, Arizona, 92.13 per cent. of the total silver recovered was extracted after 1 hour, 94.10 per cent. after 2 hours, 95.92 per cent. after 3 hours, and 100 per cent. after 4 hours. The loss in quicksilver is small, as there is no chemical loss inherent in the process; the yield is relatively high, but the bullion is liable to be low grade on account of copper being precipitated and amalgamated. When the charge has been worked the contents of the pan are discharged into a settler, in which the amalgam is separated from the sands. It has the same general construction as the pan. It is 8 feet in diameter and 3 feet deep. The bottom, slightly conical, has a groove near the circumference to catch the amalgam, which is withdrawn through a discharge spout into a bowl. In the sides, at different levels, are three discharge holes for water and sand. The muller reaches to within 3 inches of the bottom, and makes 12–15 revolutions per minute. In settling, the pulp is diluted by a small stream of water and the thinned pulp drawn off, first through the top discharge hole and then through the other two, the bottom one being about 8 inches above the amalgam. Settling takes about half the time required to work a charge in the pan, hence one settler serves two pans. The amalgam is dipped out from the bowl into a canvas bag (the strainer), to separate the excess of the quicksilver from the pasty amalgam, which is then retorted and melted. The cost of treating a ton of ore in the western part of the United States is from three to seven dollars. At some works treating ores containing sulphurets, which do not yield their silver to quicksilver, concentration apparatus (see Ore Dressing) is inserted between the stamps and the settling tanks to remove the sulphurets, which are worked by themselves; at other works they are recovered from the sands after these have left the settlers. In order to do away with the handling of the wet pulp and to obtain a higher extraction, M. P. Boss has modified the ordinary plant by making the pulp as it flows from the stamps pass through a grinding pan, then through a series of amalgamating pans, followed by a row of settlers.

A 20-stamp mill is served by 12 men in 24 hours. The Washoe process is independent of the climate, but it requires cheap power and an abundance of water.

In the *Cazo, Caldron,* or *Hot* process, the pulverized silver ore is boiled in a copper-bottomed wooden vat, first with brine, until the silver has been reduced by the copper, and then with quicksilver. The *Fondon* is an improvement on the Cazo. Bars of copper drawn over the bottom by mules or water power (like the stone drags in the arrastra) grind off fine particles of copper, which hasten the reduction of the silver and diminish the formation of calomel. In the *Kröhnke* process the silver mineral of the pulverized ore is decomposed in a revolving barrel by a hot solution of cuprous chloride in brine in the presence of zinc or lead and quicksilver.

Chloridizing Roasting. — In a chloridizing roast chlorine produces its effect as nascent chlorine or gaseous hydrochloric acid. The leading reagents are salt (NaCl), sulphur trioxide (SO_3, produced in the roasting), and water vapor (H_2O). The decomposition of salt is expressed by $2NaCl + 2SO_3 = Na_2SO_4 + SO_2 + Cl_2$. In the presence of water vapor the following reaction takes place: $2NaCl + SO_3 + H_2O = Na_2SO_4 + 2HCl$. As some water vapor is always present, hydrochloric acid will invariably be formed with the chlorine. The roasting is carried on in hand and mechanical reverberatory furnaces, occasionally in muffle furnaces. A chloridation of over 90 per cent. of the silver is the rule.

The *European Barrel,* or *Freiberg,* process (see *Encyclopædia Britannica,* Vol. XXII, p. 70), perfected at Freiberg, Saxony, was abandoned there in 1856. In the United States it was used quite extensively in Colorado and Nevada, but has now been given up. The main reasons for this are the length of time required to finish a charge, on account of the absence of any extraneous source of heat, and the great care with which operations have to be carried out in order to obtain satisfactory results. The *Reese River* process consists in dry-stamping crushed dried ore and dried salt (separately or together), charging them into a roasting furnace, and amalgamating the chlorodized ore in an iron pan. The general arrangement and construction of a mill resemble those of the Washoe process. The apparatus for drying ore and salt varies greatly, drying-floors, dry-kilns, and continuous mechanical reverberatory furnaces with stationary and revolving hearths being used. The general construction of the pan is the same as in the Washoe process; the management, however, differs. The steam-chest is not used to such an extent, as the bottom would be prematurely corroded; less water is used, as the pulp would become too

thin on account of the soluble salts (sodium chloride, sulphate, etc.) going into solution; and the roasted ore is not ground, as the hot brine readily dissolves the silver chloride from the porous ore, and thus brings it into intimate contact with iron and quicksilver. Chemical reagents are sometimes added — lime or sulphuric acid, to neutralize an excess of acid or alkali; bluestone, to form cuprous chloride with sodium chloride; and iron and zinc, to make the galvanic action more energetic and to reduce the consumption of iron. The rest of the apparatus (settler, retort, crucible, furnace) is the same as with the Washoe process. The Reese River process costs from half as much again to twice as much as the Washoe process.

The *Francke-Tina* process was developed in Bolivia for the treatment of refractory ores rich in zinc blende (ZnS) and tetrahedrite $4(Cu_2, Fe, Zn, Ag_2, Hg_2)S + (Sb, As, Bi)_2S_3$. The ore is given only a partial chloridizing roast, on account of the great loss in silver that would be caused by the formation of zinc chloride ($ZnCl_2$). The large amount of soluble sulphates of iron and copper formed in the roast is made to act upon salt charged in a copper-bottomed amalgamating pan; the chlorides formed finish in the wet way the imperfect chloridation obtained in the furnace.

Lixiviation. — Ores suited for amalgamation can, as a rule, be successfully leached. In leaching, the silver ore is subjected to the action of solvents, which dissolve the silver; from the solution the silver is precipitated and converted into a marketable product.

The leading solvents are aqueous solutions of hyposulphite salts. Sodium chloride, characteristic of the Augustin process (see *Encyclopædia Britannica*, Vol. XXII, p. 70), has almost wholly fallen into disuse; and potassium cyanide, which has become a very important solvent for finely divided gold, is rarely used in leaching silver ores. The use of sodium hyposulphite as solvent, and sodium sulphide as precipitant, was proposed in 1850 by Hauch and Percy, and put into practice in 1858 by Patera (Patera process); calcium hyposulphite with calcium polysulphide was first used by Kiss in 1860 (Kiss process, now obsolete); sodium hyposulphite with calcium polysulphide was adopted about 1880 by Hofmann (Hofmann process); finally, sodium hyposulphite with cuprous hyposulphite was first applied by Russell in 1884, who included in his process the acidulation of the first wash-water (to neutralize any harmful alkaline reaction), and the separation of lead with sodium carbonate from the silver solution previous to precipitating

with sodium sulphide. In all processes the silver ore is finely crushed, usually by rolls, as, because making few fines, they leave the ore in the best condition for leaching. As a rule the ore is subjected to a preliminary chloridizing roast, though occasionally it may be leached raw. The vats in common use are circular wooden tanks, 16–20 feet in diameter and 8–9 feet deep, if the leached ore is to be removed by sluicing; 5 feet, if by shovelling. They have a false bottom, with cloth or gravel filters. The basis of the following outline is the Patera process. The ore, supposed to have been salt-roasted, is charged loosely into the leaching vat and treated with water (to which sulphuric acid or blue vitriol may have been added) to remove soluble salts, which might later on be precipitated with the silver (base-metal chlorides), or might overcharge the solution (sodium chloride and sulphate), or might interfere with the solvent power (sodium sulphate). The vat is filled with water from above or below, in- and out-flow are then so regulated as to keep the ore covered with water. Any silver dissolved by the first wash-water is recovered by a separate treatment. After the wash-water has been drained off, the ore is ready for the silver solvent. This is a solution containing up to 2 per cent. of sodium hyposulphite ($Na_2S_2O_3 + 5aq.$) of which one part dissolves 0.485 parts of silver chloride, $= 0.365$ parts metallic silver ($2AgCl + 3Na_2S_2O_3 = Ag_2S_2O_3$, $2Na_2S_2O_3 + 2NaCl$). Silver arsenate and antimoniate are also readily soluble, metallic silver slightly so, silver sulphide not at all. (In the Russell process the double salts, $4Na_2S_2O_3.3Cu_2S_2O_3$ and $8Na_2S_2O_3.3Cu_2S_2O_3$, and the metallic silver and silver sulphide are readily soluble; thus it supplements that of Patera). After the silver has been dissolved by percolation, the last of the solvent still in contact with the ore is replaced by a second wash-water. The silver solution, collected in a circular precipitating vat (10 feet in diameter and 10 feet deep), is treated with sodium sulphide (or calcium polysulphide), unless sodium carbonate was first added to throw down any lead that had gone into solution, and which may have been present in the ore as sulphate. Silver sulphide falls out as a black mud with about 50 per cent. silver, and the solvent will be regenerated: $2Ag_2S_2O_3 + Na_2S_2 = Ag_2S + Na_4S_2O_6$ and $Na_4S_2O_6 + Na_2S_2 = 2Na_2S_2O_3 + 2S$ (or $Ag_2S_2O_3 + CaS_5 = Ag_2S + CaS_2O_3 + S_4$, and in part $CaS_2O_3 + Na_2SO_4 = CaSO_4 + Na_2S_2O_3$). If the sodium cuprous hyposulphite was used as a solvent in addition to the simple sodium hyposulphite, cuprous sulphide will be precipi-

tated with the silver sulphide, and the precipitate will be of lower grade. At some works the silver is precipitated with sodium sulphide, and the liquor, after having been separated from the silver sulphide, is treated with calcium polysulphide, that by the precipitation of calcium sulphate the accumulation of sodium sulphate may be prevented. The precipitated silver (copper) sulphide is filtered, dried, and usually shipped to silver-lead works to be refined; sometimes it is converted into metallic silver at the works. The solution, freed from silver, is used again as solvent. Lixiviation has many advantages over amalgamation. It permits coarser crushing of the ore, the cost of the plant is lower, the power required is nominal, the cost of chemicals is lower than that of quicksilver, less water is necessary, and the extraction is often higher, as silver arsenate and antimoniate are readily soluble, while they are not decomposed in amalgamation. On the other hand, silver and silver sulphide are readily amalgamated; and while they are not dissolved in the Patera process, they are in the Russell process.

Statistics. — The world's production of silver in 1900 was, according to *The Mineral Industry*, Vol. IX, p. 315, in troy ounces: United States, 59,561,797; Canada, 4,446,505; Mexico, 55,804,420; Central America, 1,446,795; Argentina, 383,561; Bolivia, 10,432,685; Chile, 5,772,791; Colombia, 2,800,000; Ecuador, 81,000; Peru, 6,590,955; Austria, 1,272,022; Hungary, 675,750; France, 466,189; Germany, 6,243,326; Greece, 1,294,917; Italy, 1,081,707; Norway, 154,389; Russia, 163,960; Servia, 18,386; Spain, 5,909,418; Sweden, 73,626; Turkey, 65,363; United Kingdom, 191,927; Dutch East Indies, 1,447; Japan, 1,810,375; Australasia, 14,063,244; other countries, 48,226; total, 180,854,781.

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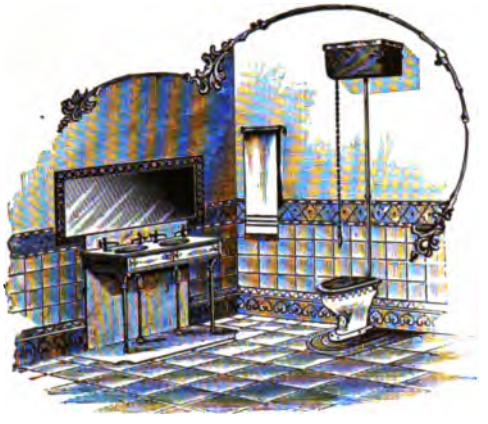

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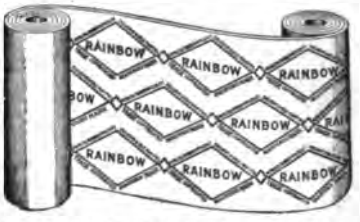

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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Edited by ROBERT P. BIGELOW, PH D.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.**

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VOL. XVI DECEMBER, 1903 No. 4

HARVARD COLL. FEB 3 19 CAMBRIDGE, M

PROCEEDINGS OF THE SOCIETY OF ARTS.

FORTY-FIRST YEAR, 1902–1903.

THE 581st regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 23, at eight o'clock, Professor Clifford in the chair. Two hundred and fifty persons were present.

After the minutes of the previous meeting had been read and approved, Mr. Francis E. Stanley addressed the Society on "Some Problems to be Solved in the Building of the Perfect Steam-propelled Automobile."

After a brief discussion a vote of thanks was tendered the speaker, and the meeting adjourned.

The 41st Annual Meeting (582d regular meeting) of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Friday evening, May 22, at eight o'clock, Professor Niles in the chair. Two hundred persons were present.

After the minutes of the previous meeting had been read and

approved, Mr. Henry E. Warren was elected to Associate Membership in the Society.

The Annual Report of the Executive Committee was read and approved.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE PRESENTED AT THE FORTY-FIRST ANNUAL MEETING OF THE SOCIETY OF ARTS, MAY 22, 1903.

The first meeting of the SOCIETY OF ARTS for the present year was held on October 9, 1902. Fourteen meetings have been held, with an average attendance of one hundred and eighty-four.

During the past year the unusual interest in the meetings of the Society which has been shown in the past few years has continued. An effort has been made to have the addresses given before the Society cover a wide range of subjects. As a consequence, nearly all the students in the Institute have had opportunity to hear men who are authorities upon the subjects in which they are preparing themselves for the future.

The following papers have been read:—

"Long Distance Electric Railroading." Professor Louis Duncan, Director of the Department of Electrical Engineering of the Institute.

"The Identification of Our Woody Plants in Winter." Mr. John G. Jack, of the Arnold Arboretum.

"The Art of Lithography." Mr. George H. Bartlett, Principal of the Massachusetts Normal Art School.

"The Designing of Small Racing Yachts." Mr. W. Starling Burgess.

"A Substance with Remarkable Optical Properties, and a Screen Transparent to Ultra Violet Light Only." Professor R. W. Wood, of Johns Hopkins University.

"The Coast Survey and its Work." Mr. O. H. Tittmann, Superintendent of the United States Coast and Geodetic Survey.

"The Reclamation of the Arid Public Lands." Mr. F. H. Newell, Chief Engineer, United States Geological Survey.

"Martinique and Mt. Pelée." Mr. George Kennan.

"Exhibition of Some New Apparatus for Illustrating Certain Electro-Magnetic Phenomena." Professor Louis Derr, of the Institute.

"Government Architecture." Mr. J. Knox Taylor, Supervising Architect, Treasury Department.

"The Composition of Sewage with Relation of Problems of Disposal." Mr. George W. Fuller, Sanitary Expert, New York City.

"The Charles River Dam." Mr. R. H. Dana.

"Some Problems to be Solved in the Building of the Perfect Steam-propelled Automobile." Mr. Francis E. Stanley.

"A Reconnaissance in the Rocky Mountains of British Columbia." Mr. Howard W. DuBois, Mining Engineer, Philadelphia.

At the beginning of the year the Associate Membership was three hundred and sixty-seven. Of these members, three have died and eight have resigned, while six new members have been elected, making the present membership three hundred and sixty-two. There are thirty-seven Life Members.

The TECHNOLOGY QUARTERLY has appeared regularly during the year under the editorship of Dr. Bigelow, with the advice and counsel of the Publication Committee. There have appeared in all twenty-eight articles besides the Proceedings of the Society. A new feature introduced this year is a series of Book Reviews, which, it is hoped, will

add interest to the QUARTERLY, and will further extend the influence of the Institute and members of the Instructing Staff. We are also indebted for valuable contributions to several of our Alumni, namely, Gerard H. Matthes, William Lincoln Smith, G. C. Whipple, and Earle B. Phelps.

GEORGE W. BLODGETT,
EDMUND H. HEWINS,
CHARLES T. MAIN,
DESMOND FITZGERALD,
JAMES P. MUNROE,
} *Executive Committee.*

The report of the Nominating Committee was read, and the following named gentlemen were elected officers of the Society for the year 1903–1904. Executive Committee: George W. Blodgett, Edmund H. Hewins, Charles T. Main, James P. Munroe, and A. Lawrence Rotch. Secretary: James F. Norris.

Mr. Howard W. DuBois then addressed the Society on "A Reconnaissance for the Platinum Metals in the Rockies of British Columbia." The lecture was illustrated with a large number of lantern slides, which had been colored by a new method devised by Mr. DuBois.

A vote of thanks was tendered the speaker, and the meeting adjourned.

J. F. NORRIS, *Secretary.*

ORE DRESSING, OR THE MECHANICAL PREPARATION OF ORES.[1]

By ROBERT H. RICHARDS.

When the miner hoists his ore to the surface, the contained metal may be either in the native uncombined state or combined with other substances, forming minerals of more or less complex composition. In both cases the valuable mineral is always associated with minerals of no value. The province of the ore dresser is to separate the "values" from the waste by mechanical means, obtaining thereby "concentrates" and "tailings." The province of the metallurgist is to extract the pure metal from the concentrates by chemical means, with or without the aid of heat. There are also a number of non-metallic minerals which do not have any value, or at best do not reach their highest value until they have been subjected to some form of mechanical preparation; among them are diamonds, graphite, corundum, garnet, asbestos, and coal. Ore dressing, for the purposes of this article, may be divided into three parts: (1) Properties of minerals which render aid in their separation. (2) Simple operations. (3) Operations combined to form processes or "mills."

1. **Properties.** — The *specific gravity* of minerals varies greatly, some being heavy, others light. The rate of settling in water is affected by the specific gravity in this way: of two particles of the same size but different specific gravity, the heavier settles more rapidly than the lighter; while of two particles of different specific gravity which settle at the same rate in water, that of higher specific gravity is of smaller diameter than the other. The same statements are true in regard to settling in air, and in regard to momentum in air when the particles are thrown out in a horizontal direction. *Color*, *lustre*, and *fracture* are of especial value in hand-picking to aid the eye in selecting the mineral sought. Instances are: of colors, the white of quartz,

[1] Reprinted by permission of the publishers from the article, "Ore Dressing," by Prof. R. H. Richards, in the new volumes of the *Encyclopædia Britannica*. Copyright 1902. The Encyclopædia Britannica Company.

the pale straw color of feldspar, the dull yellow of limonite, the brass yellow of chalcopyrite, the pale metallic yellow of pyrites; of lustres, the vitreous of quartz, the adamantine of diamond and cerussite, the resinous of blende, the earthy of limonite, and the metallic of pyrite; and of fractures, the cleavage planes of feldspar and galena, the conchoidal fracture of quartz and pyrite, the granular of some forms of magnetite and blende. *Magnetism* is a most direct and simple method of separating minerals where it is available. The discovery that, by the use of electro-magnets of great power, minerals formerly regarded as non-magnetic are attracted has made it possible to separate several classes of minerals present in an ore; for example, the strongly magnetic mineral may first be taken out, then the mildly magnetic, and last the weakly magnetic, the non-magnetic being left behind. *Adhesion* acts when brightly burnished particles of gold, issuing with the sand from the stamp mill, come in contact with an amalgamated copper plate, for they are instantly plated with mercury and adhere to the copper, while the sand is carried forward by the water. In this way a very perfect separation of the gold from the sand is effected. In the South African diamond fields it has been found that, if the diamond-bearing sand is taken in a stream of water over a smooth surface covered with a suitable coating of grease, the diamonds will adhere to the grease while the sand does not. *Decrepitation* is the property possessed by some minerals of flying to pieces when heated suddenly. If, for example, blende and barite occur together in a product where the grains are about the same size, they cannot be separated by water, being of nearly the same specific gravity, but when dropped upon a heated iron plate the barite flies into small particles, and can then be separated from the blende by sifting. This principle, however, can only rarely be applied.

2. **Simple Operations.** — The concentration of ores always proceeds by steps or stages. Thus the ore must be crushed before the minerals can be separated, and certain preliminary steps, such as sizing and classifying, must precede the final operations which produce the finished concentrates. The more important of these simple operations will now be described.

The ore as mined contains the valuable minerals attached to and enclosed in lumps of waste rock. The province of *crushing*, or disintegrating, is to sever or unlock the values from the waste, so that the methods of separation are then able to part the one from the other.

In crushing ores it is found wise to progress by stages, coarse crushing being done best by one class of machine, medium by another, and fine by a third. Coarse crushing is accomplished by *breakers* of the Blake type (Figure 1) or of the Gates-Comet type (Figure 2). All of these machines break by direct pressure caused by a movable jaw (*a*, Figures 1 and 2) approaching towards and receding from a fixed jaw (*b*). The largest size ever fed to a breaker is 24 inches in diameter, and the smallest size to which the finest crushing commonly done by these machines brings the ore is about $\frac{3}{4}$ inch in diameter. The machine is generally supplied with ore in lumps not larger than 9 inches in diameter, and crushes them to about $1\frac{1}{2}$ inches in diameter. Medium-size crushing is done mostly by rolls (Figure 3) or steam stamps. *Rolls* (Figure 3) crush by the ore being drawn by direct pressure caused rolls held closely to-between two revolving least fine slimes, or *fines*, gether. They make the quent treatment, and are to be lost in the subse- all brittle minerals. therefore preferred for works upon the same

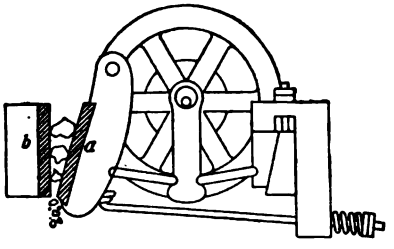

FIG. 1.—BLAKE BREAKER.
a, movable jaw; *b*, fixed jaw.

The *steam stamp* hammer, the pestle principle as a steam being forced down by steam pressure acting through piston and cyl- inder with great crush- ing force in the mortar. Steam stamps have been very successful with na- tive copper rock because they break up the little leaves, flakes, and filaments of copper, and render them susceptible of concentration, which rolls do not. Fine crushing is done by gravity stamps, by pneumatic stamps, by centrifugal roller mills, by amalgamating pans, by ball mills, by Chile edgestone mills, and by arrastras.

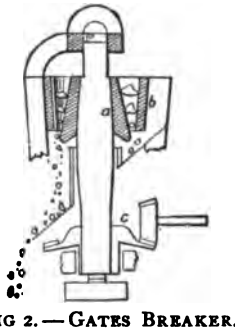

FIG 2.—GATES BREAKER.
a, movable jaw; *b*, fixed jaw; *c*, gear with eccentric hub and with loose fit on the spindle.

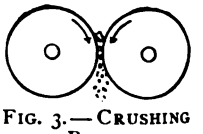

FIG. 3.—CRUSHING ROLLS.

The *gravity stamp* (Figure 4) is a pestle of 800 pounds weight, more or less, which is lifted by a revolving cam, and falls by the force of gravity to strike a heavy blow in the mortar and do the work of crushing; the frequent revolution of the cam gives a more or less rapid succession

of blows. Gravity stamps are especially adapted to the fine crushing of gold ores, which they reduce to $\frac{1}{80}$ inch, and sometimes even to $\frac{1}{80}$ inch grains. The blow of the stamp upon the fragments of quartz not only liberates the fine particles of gold, but brightens them so that they are quickly caught upon the amalgamated plates. The pneumatic stamp has a heavy pestle, which is moved up and down by direct connection with a crank; but since the height of the ore in the mortar varies, the pestle must have the means also of varying its movement to avoid breakage. To this end an air cylinder with piston is inserted in the stem, the elasticity of the air within the cylinder not only giving the needed variation of throw, but increasing the force of the blow in the mortar. The *centrifugal roller mills* are suited to fine crushing of middle products, namely, by-products composed of grains containing both values and waste, since they avoid making such fine slimes. They crush by the action of a roller, rolling on the inside of a steel ring, both having vertical axes. The *amalgamating pan* is suitable for grinding silver ores for amalgamation where the finest grinding is sought, together with the chemical action from the contact with iron. It crushes by a true grinding action of one surface sliding upon another. The *Chile edgestone mill* is employed for the finest grinding ever used preparatory to concentration. The *arrastra*, or drag-stone mill, grinds still finer for amalgamating.

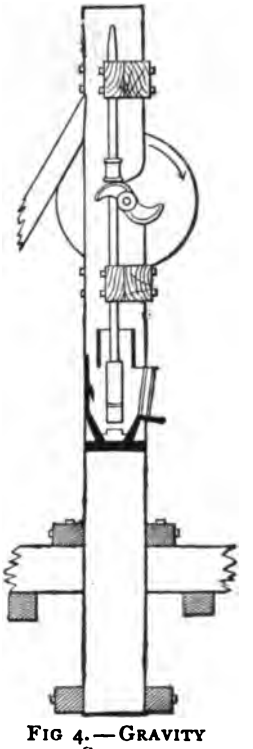

FIG 4. — GRAVITY STAMP.

A considerable class of workable minerals, among which are surface ores of iron and surface phosphates, contain worthless clay mixed with the valuable material, the removal of which is accomplished by the *log washer*. This is a disintegrator, consisting of a long, narrow cylinder revolving in a trough which is nearly horizontal. Upon the cylinder are knives or paddles set at an angle, which serve the double purpose of bruising and disintegrating the clay, and of conveying the cleaned lump ore to be discharged at the upper end of the trough, the water meanwhile washing away the clay at the lower end.

Roasting for Friability. — When two minerals — for example,

pyrites and cassiterite — one of which is decomposed and rendered porous and friable by heat and oxygen, are roasted in a furnace, the pyrites become porous oxide of iron, while the cassiterite is not changed. A gentle crushing and washing operation will then break and float away the lighter iron oxide, leaving the cassiterite behind.

Sizing. — If crushed ore be sifted upon a screen with holes of definite size, two products will result: the *oversize*, which is unable to pass through the screen, and the *undersize*, which does pass. If the latter size be sifted upon another screen with smaller holes, it will again make oversize and undersize. Rittinger adopted for close sizing the following diameters, in millimeters, for the holes in a set of screens: 64, 45.2, 32, 22.6, 16, 11.3, 8, 5.6, 4, 2.8, 2, 1.4, 1. Each of these holes has an area double that of the one next below it; this may be called the screen ratio. A process which does not need such close sizing might use every alternate screen of the above set, and in extreme cases even every fourth screen. In mills the screen ratio for coarse sizes often differs from that for fine. Sizing is done by cylindrical screens revolving upon their axes (Figure 5), by flat, shaking screens, and by fixed screens with a comparatively steep slope. Wire cloth with square holes and steel plate punched with round holes are both used. To remove the largest lumps in the preliminary sizing, fixed bar screens are preferred on account of their strength and durability. Sizes smaller than can be satisfactorily handled by screens are treated by means of *hydraulic classifiers* and *box classifiers* (*Spitzkasten*). The lower limit of screening and, therefore, the beginning of this work varies from grains of 5 millimeters to grains of 1 millimeter in diameter. An hydraulic classifier (Figure 6) is a trough-like washer through which the water and sand flow from one end to the other. In the bottom, at regular intervals, are pockets, or pits, with hydraulic devices which hinder the outflowing discharge of sand (*b*) by an inflowing stream of water (*a*). By regulating the speed of these currents of water, the size of the grains in the several discharges can be regulated, the first being the coarsest, the overflow at the end the finest. Box classifiers are

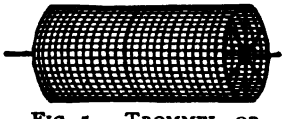

FIG. 5. — TROMMEL, OR REVOLVING SCREEN.

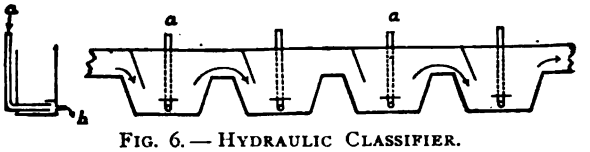

FIG. 6. — HYDRAULIC CLASSIFIER.

similar, except that the pockets are much larger and no inflowing clear water is used; they, therefore, do their work much less perfectly. Classifiers do not truly size the ore, but merely class together grains which have equal settling power. In any given product, except the first, the grain of high will always be smaller than that of low specific gravity. The box classifiers are suited to treating finer sizes than the hydraulic classifiers, and therefore follow them in the mill treatment.

Picking floors are areas on which men, boys, or girls pick out valuable mineral which is rich enough to ship at once to the smelter. The picking is often accompanied and aided by breaking with a hammer. *Picking tables* are generally so constructed that the pickers can sit still and have the ore pass before them on a moving surface, such as a revolving circular table or traveling belt. Stationary picking tables require the ore to be wheeled to and dumped in front of the pickers. Picking out the values by hand has the double advantage that it saves the power and time of crushing, and prevents the formation of a good deal of fine slimes which are difficult to save.

Jigs treat ores ranging from $1\frac{1}{2}$ inches in diameter down to $\frac{1}{60}$ inch. If an intermittently pulsating current of water is passed up through a horizontal sieve on which is a bed of ore, the heavy mineral and the quartz quickly form layers, the former beneath the latter. The machine by which this is done is called a jig (Figure 7), and the operation is called jigging. The pulsating current is obtained by placing a vertical longitudinal partition (*c*) extending part of the way down to the bottom of the jig box. The sieve (*a*) is firmly fastened on one side of the partition, and on the other a piston (*d*) is moved rapidly up and down by an eccentric, causing an up-and-down current of water through the sieve (*a*). The sieve is fed at one end (*e*) with a constant supply of water and ore, and the quartz overflows at the other. The constantly accumulating bed of concentrates is either discharged through the sieve into the space below (*g*), called the hutch, or by some special device at the side. On jigs, where the concentrates pass through the sieve, a bed of heavy mineral grains, too large to pass, holds back the lighter quartz. The quartz overflow from one sieve (*a*) generally carries too much value to be thrown away, and it is, therefore, jigged again upon a second sieve (*b*). In

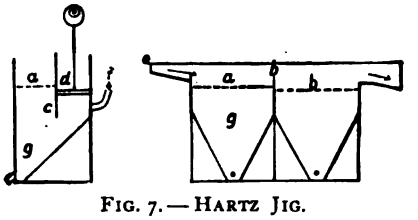

FIG. 7. — HARTZ JIG.

jigging difficult ores, three, four, five, and even six sieves are used. A succession of sieves gives a set of products graded both in kind and in richness, the heavier mineral, as galena, coming first, the lighter, as pyrites and blende, coming later. The best jigging is done upon closely sized products, using a large amount of under-water added beneath the sieve. Very good jigging may, however, be done upon the products of hydraulic classifiers, where the heavy mineral is in small grains and the quartz is large, by using a bed on the sieve and diminished under-water, which increases the suction, or downward pull by the returning plunger.

Bumping Tables. — Rittinger's table is a rectangular, gently sloping plane surface, which by a bumping motion throws the heavy particles to one side while the current of water washes down the quartz to another, a wedge-shaped divider separating and guiding the concentrates and tailings into their respective hoppers. The capacity on pulp of $\frac{1}{80}$ to $\frac{1}{50}$ inch size is some four tons in twenty-four hours. In the Wilfley table (Figure 8), and those derived from it, a gentler vanning motion is substituted for the harsh bump; they have a greatly increased width and a set of riffle blocks (*b*) at right angles to the direction of flow (*c*), tapering in height towards the side where the concentrates are discharged (*d*). This combination has produced a table of great efficiency and capacity for treating grains from $\frac{1}{8}$ inch in diameter down to $\frac{1}{200}$ inch, or even finer. The capacity on $\frac{1}{30}$-inch pulp is from 15 to 25 tons in twenty-four hours.

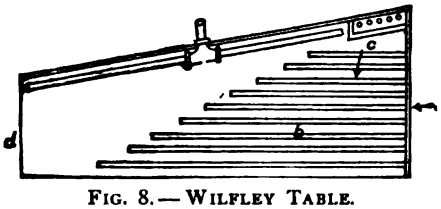

FIG. 8. — WILFLEY TABLE.

Vanners are machines which treat ores on endless belts, generally of rubber, with flanges on the two sides. The belt (Figure 9) travels up a gentle slope (*a*) on horizontal transverse rollers, and is shaken about two hundred times a minute, either sidewise or endwise, to the extent of about one inch. The lower 10 feet is called the concentrating plane (*b*), and slopes 2.78 per cent., more or less, from the horizontal; the upper 2 feet of length is called the cleaning plane (*c*), and slopes 4.45 per cent., more or less. The ore is fed on with water at the intersection of the two planes (*d*). The vibra-

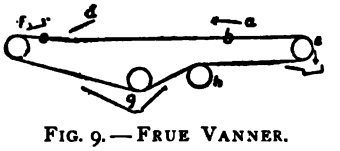

FIG. 9. — FRUE VANNER.

tion separates the ore into layers, the heavy beneath and the light above. The downward flow of the water carries the light waste off and discharges it over the tail roller (*e*) into the waste launder, while the upward travel of the belt carries up the heavy mineral. On the cleaning plane the latter passes under a row of jets (*f*) of clean water, which removes the last of the waste rock. The heavy mineral clings to the belt while it passes over the head roller, and only leaves it when the belt is forced by the dipping roller to dip in the water of the concentrates tank (*g*). The cleaned belt then continues its return journey over the guide roller (*h*) to the tail roller (*e*), which it passes around, and again does concentration duty. Experience proves that for exceedingly fine ores the end-shake, with steep slope and rapid travel, does better work than the side-shake vanner. For ordinary gold stamp-mill pulp, where cleanness of tailings is the most important end, and where to gain it the engineer is willing to throw a little quartz into the heads, the end-shake vanner is again probably a little better than the side-shake, but where cleanness of concentrates is sought the side-shake vanner is the most satisfactory.

Slime tables are circular revolving tables (Figure 10) with flattened conical surfaces and a slope of $1\frac{1}{8}$ inches, more or less, per

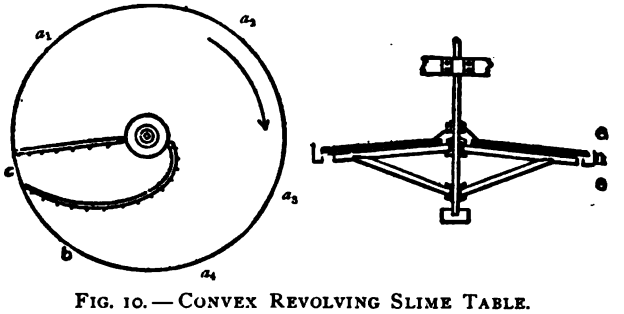

FIG. 10. — CONVEX REVOLVING SLIME TABLE.

foot from center to circumference; a common size is 17 feet in diameter, and a common speed one revolution per minute. These tables treat material of $\frac{1}{100}$ inch and less in diameter coming from box classifiers. The principle on which the table works is that the film of water upon the smooth surface rolls the larger grains (quartz) towards the margin of the table faster than the smaller grains (heavy mineral) which are in the slow-moving bottom current. The material is fed at the centre over one-half the circumference on the side a_1 a_2.

The revolution of the table then discharges the quartz earlier at a_1 a_2 a_3 a_4, an intermediate middling product next at *b*, and the heavy mineral last at *c*. Suitable waste launders and catch boxes are supplied for the three products. The capacity of such a table is 12 tons or more of pulp, dry weight, in twenty-four hours. *Frames* are rectangular slime tables which separate the waste from the concentrates on the same principle as the circular tables, though they run intermittently. They treat very fine pulp, and after being fed for a short period (about fifteen minutes) the pulp is shut off, the concentrates are flushed off with a douche of water and caught in a box, and the feed pulp is again turned on. They are much used in the Cornish tin works. *Canvas tables* are rectangular tables with plane surfaces covered with cotton duck (canvas), free from seams; they slope about $1\frac{1}{2}$ inches to the foot. They are fed with stamp-mill pulp, with the tailings of vanners, or, best of all, with very fine pulp overflowing from a fine classifier. The rough surface of the duck is such an efficient catching surface, that they can run for an hour before the concentrates are removed — an operation which is effected by shutting off the feed pulp, rinsing the surface with a little clean water, and hosing or brooming off the concentrates into a catch box. The feed pulp is then again turned on and the work resumed. They have been more successful than any other machine in treating the finest pulp, especially when their concentrates are finally cleaned on a steep-slope end-shake vanner.

Buddles act in principle like slime tables, but they are stationary, and they allow the sand to build itself up upon the conical surface, which is surrounded by a retaining wall. When charged, the tailings are shoveled from the outer part of the circle, the middlings from the intervening annular part, and the concentrates from the inner part. They treat somewhat coarser sizes than the slime table. When wooden blocks or cobble stones of uniform size are placed in the bottom of a sluice, the spaces between them are called *riffles;* and when gold-bearing gravel is carried through the sluice by a current of water a great many eddies are produced, in which the gold and other heavy minerals settle. The *kieve, or dolly tub,* is a tub as large or larger than an ordinary oil barrel, with sides flaring slightly upwards all the way from the bottom. In the center is a little vertical shaft, with hand crank at the top and stirring blades like those of a propeller at the bottom. Fine concentrates from buddles or slime tables are

still further enriched by treatment in the kieve. The kieve is filled perhaps half full of water, and the paddles set in motion; concentrates are now shoveled in until it is nearly full, the rotation is continued a little longer, and then the shaft is quickly withdrawn and the side of the kieve steadily thumped by a bumping bar as long as settling continues. When this is completed, the water is syphoned off, the top sand skimmed off and sent back to the buddle, and the enriched bottom material shoveled out and sent to the smelter.

3. **Combined Operations.** — In designing concentration works, the millwright seeks so to combine the various methods of coarse and fine crushing, and of preliminary and final concentration, that he may obtain the maximum return from the ore with the minimum cost. Some of the more important of these mill schemes will now be described.

The hand-jig process used for the zinc and lead ores of Missouri is first to clean the ore from adhering clay by raking it back and forth in a sluice with a running stream of water, and then shoveling it upon a sloping screen with holes of about one inch, where it yields oversize and undersize. The former is hand-picked into lead ore, zinc ore, and waste, while the latter is jigged upon a hand jig, and yields several layers of minerals removed by a hand skimmer. The top skimmings are waste, the middle skimmings come back with the next charge to be jigged over, and the bottom skimmings go to a second jig with finer screen. The coarsest of the hutch product goes to the second jig; the finest is sold to a sludge mill. The second jig makes top skimmings, which are sent back to the first jig; middle skimmings, which are zinc concentrates; and bottom skimmings and hutch, which are both lead concentrates. In *the Missouri zinc-concentrating mill* the ore carrying blende and calamine, with a little galena, is in very large crystallization, and contains, when crushed, very little in the way of included grains. It is crushed by Blake breaker and rolls to pass through a sieve with holes $\frac{3}{4}$ inch in diameter, and is then treated on a jig with six consecutive sieves, yielding discharge and hutch products from each sieve, and tailings to waste. The earlier discharges are finished products, while the later are re-crushed and then re-treated on the same jig. The hutch products are treated on a finishing jig with five sieves, and yield galena from the first discharge, and hutch and zinc ore from the others. The capacity of such jigs is very large, even to 75 or 100 tons per day of ten hours.

In *the diamond washing* of Kimberley, South Africa, the material taken from the mine is weathered by exposure to the air and rain for several months, and the softening and disintegration thus well started are completed by stirring in vats with water. Breaker and rolls were tried in order to hasten the process, but the larger diamonds were broken and ruined thereby. The material from the vats is screened and jigged, and of the jig concentrates containing about 2 per cent. of diamonds the coarser are hand-picked and the finer are treated on a greased surface.

Lead and copper ores contain their values in brittle minerals, and are concentrated in mills which vary somewhat according to local conditions; the one here outlined is typical of the class. The ore is crushed by breaker and rolls, and separated into a series of products diminishing in size by a set of screens, hydraulic classifiers, and box classifiers. All the products of screens and hydraulic classifiers are jigged on separate jigs, yielding concentrates, middlings, and tailings; those of the box classifier are treated on the slime table, vanner, or Wilfley table, yielding concentrates and tailings, and perhaps middlings. The coarser middlings contain values attached to grains of quartz, and are therefore sent back to be re-crushed and re-treated. The finer middlings contain values difficult to save only on account of their shape — for example, flat grains — and are sent back to the same machine or to another to be finished.

The *native copper rock of Lake Superior* is broken by powerful breakers, sometimes preceded by a heavy drop hammer weighing nearly a ton. The operation is accompanied by hand-picking, yielding rich nuggets with perhaps 75 per cent. of copper ready for the smelter; at some mines a second grade is also picked out, which goes to a steam finishing hammer, and yields cleaned mass copper for the smelter and rich stamp stuff. The run of rock which passes by the hand pickers is of a size that will pass through bars 3 inches apart, and goes to the steam stamps. The stamps crush the rock to pass through a screen with round holes $\frac{3}{16}$ inch in diameter. This sand is treated in hydraulic classifiers with four pockets, the products from the pockets, being jigged by four roughing jigs yielding finished mineral copper for the smelter, included grains for the grinder, partially concentrated products for the finishing jigs, and tailings which go to waste. The overflow of the hydraulic classifier runs to a tank, the overflow of which is sent to waste in order to diminish the quantity of water, while the discharge

from beneath, treated upon slime tables, yields concentrates, middlings, and tailings. The middlings are re-treated. The stamp mortars are cleaned out periodically, even several times a day, and yield rich nuggets of copper and also unfinished material, which is sent back to the mill. Putting all the finished concentrates together, they will assay from 60 to 80 per cent. of copper according to circumstances. The extraction from the rock is from 50 to 80 per cent. of the copper contained in it.

Cornwall Tin. — Tinstone in Cornwall occurs associated with sulphides, wolfram, quartz, feldspar, slate, etc., and is broken by spalling hammers to 3-inch lumps. Hammers make less slimes than the rock breakers, and they also break the ore more advantageously for the hand-picking. The latter rejects waste, removes as far as possible the hurtful wolfram, and classes the values into groups according to richness. Gravity or pneumatic stamps then crush the ore to $\frac{1}{50}$ inch, and it is then treated on stripes (a species of long, rectangular buddle), which yield heads, middlings, tailings, and fine slimes; the first three are sent separately to circular buddles and the last to frames. The buddles yield heads, middlings, and tailings; the middlings are re-treated, the tailings are all waste; the heads are still further enriched by kieves, which yield tops to the buddle again and bottoms to be shipped to the smelter. The fine slimes are treated on frames, the concentrates of which go to buddles; of these the heads go to kieves.

The *Missouri zinc-lead sludge mill* takes the finest part of the hutch product of the hand jigs. The treatment begins on revolving screens with two sizes of holes — 25 millimeters and 1 millimeter; these take out two coarser sizes, of which the coarsest is waste and the other is jigged, yielding concentrates and waste. The main treatment begins with the finest size, which is much the largest product. It is fed to a convex circular buddle (first buddle), and yields a coarser product at the outer and a finer product in the inner part of the circle. The finer product is treated by a series of buddlings which vary somewhat, but in general are as follows: fed to a second buddle, it yields zinc and lead ore in the centre, next zinc ore, then middlings, which come back, and, outside of all, tailings. The zinc-lead ore is set to one side until enough has accumulated to make a buddle run, when it is run upon a third buddle, yielding in the central part pure lead concentrates, next lead ore (which is returned to this treatment), next zinc ore, and, outside of all, a zinc product, which is fed to the second

buddle. The coarse outside product of the first buddle is treated in much the same way as the fine, but it yields practically no lead-zinc product, which simplifies the series of buddlings necessary.

Gold Mill. — Gold ores usually contain their value in two conditions — the free gold, which can be taken out by mercury, and the combined gold, in which the metal is either coated with or combined with compounds of sulphur, tellurium, etc. The usual gold-milling scheme is to crush the ore by rock breaker to about $1\frac{1}{2}$ inches in diameter, and then to crush with water by gravity stamps, a little mercury being added to the mortar from time to time to begin the amalgamation at the first moment the gold is liberated. The pulp leaves the mortar through a screen with holes or slots $\frac{1}{80}$ to $\frac{1}{50}$ inch in width, and is then passed over amalgamated plates of copper or silver-plated copper. The free gold, amalgamated by the mercury, adheres to the mercurial surface on the plate; the rest of the pulp flows on through mercury traps set to catch any of the mercury which drains off the end of the plate. The plates and mortar are periodically cleaned up, the plates being scraped to recover the amalgam and leave them in good condition to do their work; if plates are used inside the mortar they are cleaned in the same way. The residue of partly crushed ore in the mortar, with amalgam and free mercury scattered through it, is ground for a time in a ball mill, panned to recover the amalgam, and returned to the mortar. The pulp flowing away from the mercury traps flows to a Frue vanner, or Wilfley table, on which it yields concentrates for the chlorination plant or the smelter and tailings; the latter are waste when the heavy mineral is of low grade, but if the vanner concentrates are of high grade they still contain values in very fine sizes, which can and should be saved. Improved methods for saving this material have been made recently in California. The vanner tailings are sent to a fine classifier, from which the light overflow only is saved; this is treated upon canvas tables, yielding concentrates and tailings, and these concentrates, treated upon a little end-shake vanner with steep slope and rapid travel, give clean, very fine, high grade concentrates for the chlorination works.

Iron Ore. — The brown ores of iron from surface deposits are contaminated with a considerable amount of clay and some quartz. The crude ore from surface pits or shallow underground workings is treated in a log washer, and yields the fine clay, which runs to waste, and the coarse material, which is caught upon a screen and hand-picked, to free

it from the little quartz, or jigged if it contains too much quartz. The magnetic oxide of iron occurs associated with feldspar and quartz, and can often be separated from them by the magnet. The ore, after being broken by breaker and rolls to a size varying from $\frac{1}{6}$ to $\frac{1}{16}$ of an inch in diameter, goes to a magnetic machine, which yields (1) the strongly magnetic, (2) the weakly magnetic, and (3) the non-magnetic portions. The second, or middlings, product contains grains of magnetite attached to quartz, and is, therefore, re-crushed and sent back to the magnets; the strongly magnetic portion is shipped to the furnace, and the waste to the dump heap. In concentrating certain zinc sulphides, siderite (carbonate of iron) follows the zinc and would seriously injure the furnace work. By a carefully adjusted roasting of the product in a furnace, the siderite is converted into magnetic oxide of iron, and can then be separated from the zinc ore. A special magnet of very high power has been designed for treating the franklinite of New Jersey — a mineral which is non-magnetic in the usual machines. The ore, crushed by breaker and rolls and hand-picked to remove garnet, is treated upon a belt with a roughing magnet to take out the most magnetic portion, and is then very closely sized by screens with 16, 24, 30, and 50 meshes per linear inch, respectively. The several products are fed to separate magnetic machines, yielding the franklinite, which is treated by the zinc-oxide grates, and afterward by the spiegel furnace; the residue, which is jigged, and yields the zinc silicate and oxide for the smelter furnaces and waste carrying the calcite, quartz, and mica.

Gold dredging is the method employed for saving the values from gold-bearing sand and gravel in river bottoms. A flat boat is built, provided with guy ropes or spuds, or both, for holding it still. The spuds are vertical posts, or legs, which can be forced down by powerful tackles through sockets in the boat, and so lift it, as it were, upon legs. At one end of the boat is a powerful endless-chain bucket-dredge, which scrapes the gravel from the bottom and elevates it to a revolving screen in the boat. This, in turn, sifts out the bowlders, which are at once elevated to the bank of the river, while the fine material flows over tables covered with cocoa matting, which acts like fine riffles, catching the gold in the interstices. The matting is periodically lifted up and thoroughly rinsed off. The rinsings are panned for gold, and the matting returned for another charge. The fine sand and gravel passing over the end of the tables is sent by the elevator to the river bank.

Asbestos, when of good quality, is in compact masses, which by suitable bruising and beating are resolved into fine, flexible fibers. The Canadian asbestos is associated with serpentine. It is crushed by breakers to $\frac{3}{4}$ inch, and then screened on $\frac{1}{16}$-inch screens to reject fines. The values are removed by hand-picking, and are crushed by rolls carefully set so as not to break the fiber. This product is then sized by screens, and the various sizes are sent to the Cyclone pulverizer, which by beating liberates the individual fibers. It then goes to a screen with eleven holes to the linear inch, and yields a granular undersize and oversize, and also a fibrous oversize which is drawn off by a suction fan to a settling chamber with air outlets covered by fine screen cloth. This fibrous product is the clean mineral for the market. A special treatment separates the fibers of different lengths.

The usual method of dressing *corundum and emery*, after the preliminary breaking, is to treat the material in an edgestone mill fitted with light wooden rollers. The action is that of grinding one particle against another, whereby the talc, chlorite, mica, etc., are worn off from the harder mineral. A constant current of water carries off the light impurities. This is called the "muller" process. At Corundum Hill, North Carolina, the first step in removing the impurities from "sand" corundum is to subject it to the scouring action of a stream of water while it is being sluiced from the mine to the mill, the action being increased by several vertical drops of 5 to 10 feet in the sluice. After reaching the mill, all that will not pass through a 14-mesh screen is crushed by rolls, and the undersize of the screen is treated in a washing trough; this removes part of the light waste, and the "mullers" mentioned above complete the cleaning.

Graphite occurs in schist, but being of less specific gravity than the other minerals which enter into the composition of the schist, it settles later than they do. It also breaks into thin scales, which reduces its settling rate still further. The ore is broken by breakers and by Chile edgestone mills or by gravity stamps to a size varying with the character of the minerals, the size varying from perhaps $\frac{1}{20}$ to $\frac{1}{60}$ inch in diameter. The pulp is then conveyed through a series of settling tanks, of which the later are larger than the earlier. The quartz and other waste minerals settle in the earlier tanks, while the graphite settles later; the latest tank gives the best graphite. In the Dixon Company's works in New York some forms of concentrators are believed to have replaced the slower settling tanks.

Gold Hydraulicking. — The gold contained in superficial gravel deposits is saved by one of the several schemes included in hydraulicking. A source of water power with very high head furnishes the water to a powerful jet called a "giant"; this washes down the gravel bank, and conveys the coarse and fine material first to a head sluice with riffles, which may be 100 feet or more long, and then to a tail sluice, also with riffles, which may be several miles long. Periodically — once a month, perhaps — the head sluice is cleaned up, the riffle blocks being removed and cleaned, and the sand which is washed down and caught in a temporary tank at the foot panned for its gold with hand pans. The riffle blocks are then replaced and work proceeds as before. At the end of the season the long tail sluice also is cleaned up in the same way. Gravel containing five cents a cubic yard has in places paid well.

The *phosphates* of Florida are of four kinds: hard rock, soft rock, land pebble, and river pebble. The hard rock is crushed by toothed rolls and cleaned in log washers. The washed product is screened; the sizes finer than $\frac{1}{16}$ inch are thrown away because too poor; the other sizes are dried and sold, some waste having been picked out of the coarsest. The soft rock is simply dried, ground, and sold. Land pebble is treated by log washers, any clay balls remaining being removed by a screen, and the phosphate dried and sold. In special cases land pebble is treated by hydraulicking, followed by a log washer, and this again by a powerful jet washer, to remove the last of the clay. River pebble is taken from the river by centrifugal pumps, and screened on two screens with 1-inch and $\frac{1}{16}$-inch holes, respectively; the oversize of the first sieve and the undersize of the second sieve are thrown away because of too low grade.

SCHOOL LABORATORY WORK: A FREE-MILLING GOLD RUN.[1]

By ROBERT H. RICHARDS and E. E. BUGBEE.

FRIENDS often ask how accurate the work of our little stamp mill is, or express the opinion that a little mill cannot do good work. As a reply we would like to place on record the results of a few tests.

There are two periods of work in our laboratory: the fall term, when the class collectively goes through all our chief laboratory processes; and the spring term, when the students work up their theses, each electing some one process or investigation, and devoting himself wholly, or almost wholly, to that.

Some of the tests, the results of which are recorded in this paper, were made in the fall term; the preparation of the apparatus, the sampling, and the assaying being done largely by assistants, with the aid of the students. Others were made in the spring term as thesis work, and the results are due wholly to the students.

The complete "tree" of our process is patterned after the most approved California mill practice. It is modified only where the small-scale method must differ from the large, in order to secure results from a brief test lasting a few hours, followed, perhaps, by an interval of many months between tests, which seek to rank in accuracy with those of the large-scale work, running over months and years of continuous work, broken only by brief intervals for cleaning up.

We use no battery plates, because we believe the loss due to absorption of gold by the copper may be greater than the gain from using them.

We use silver amalgam on our apron plate, painting it on before the run and scraping it off with the gold contents afterwards, for two reasons: it renders the plate very quick to catch gold, and it renders the loss from absorption by the copper plate insignificant, or prevents it altogether.

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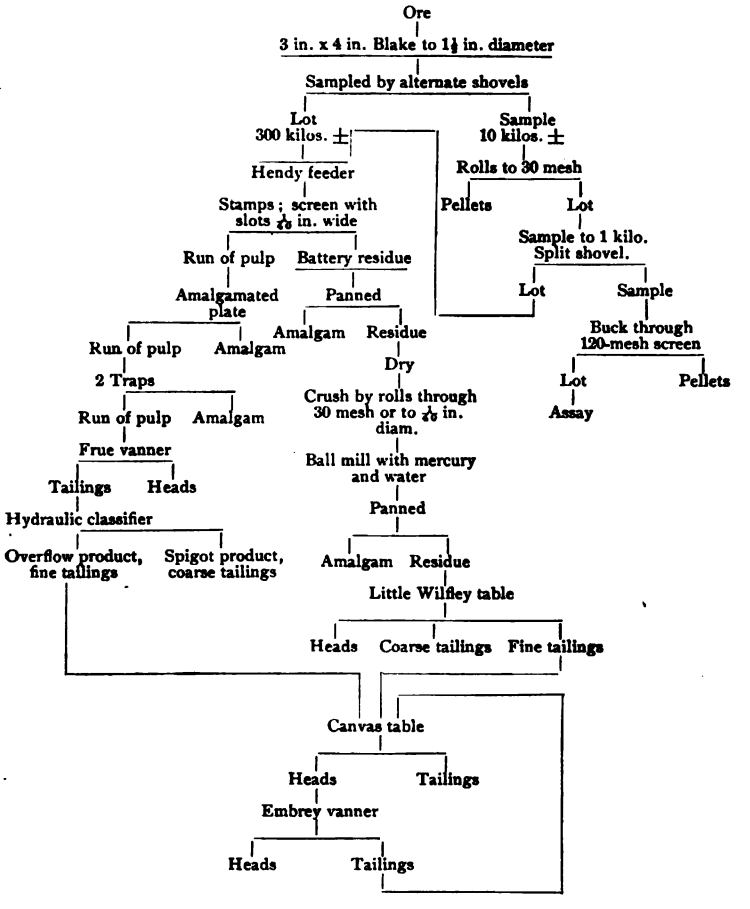
[1] Reprinted from the *Transactions of the American Institute of Mining Engineers*, Albany meeting, February, 1903.

Tree of Process.



Our canvas and fine vanner plant for treating the extremely fine tailings is that known as the Gates canvas plant, originally designed by G. G. Gates and installed at the Kennedy mine, Jackson, California. Since it has been demonstrated clearly that this canvas plant can pay only when the assay of concentrates is high or when the percentage of concentrates is large, we do not always choose this run as the one to illustrate to students the wonderful catching power of canvas for extremely fine concentrates. We do, however, make it our practice to separate, by classifying, the coarse Frue-vanner tailings from the fine, thereby preparing for canvas should we decide to use it.

Sampling. — Many of the ores we run would come under the head of "rich spotty" ores, as the Colorado phrase is. To crush and cut

down such an ore, according to best Colorado rules of sampling, would require breaking the whole batch of from 500 to 1,000 pounds down to 10 or even 30 mesh. This would ruin our gold stamp-mill run. We are thus put in the odd position of having to choose between sampling the lot according to the best rules for safe work and spoiling the stamp run, or of making a stamp-mill run, using only a very crude sample for valuation, which we could not possibly defend on the score of accuracy. It is needless to say we choose the latter method.

The mill and vanner were run under the following conditions:

Apron plate of copper 6 feet long, 2 feet wide, covered with silver amalgam; number of stamps, 3; weight of each stamp, 225 pounds; diameter of shoe, 5.75 inches; number of drops, 98 per minute; height of drop, from 4.25 to 5.75 inches; height of discharge, 4.75 inches; screen, horizontally slotted, openings $\frac{1}{40}$ inch wide; rate of crushing, 57 to 94 kilos. per hour; plate slope, 1.5 inches per foot; feed water to the battery, 15 kilos. per minute; wash water on vanner, from 4 to 8 kilos. per minute; Frue vanner slope, 3.5 to 4.5 inches in 12 feet; number of shakes, 198 per minute; belt travel, from 40 to 60 inches per minute; canvas table, 10 feet long, 4 feet wide; canvas-table slope, 1.5 inches per foot; canvas-table feed, 10 kilos. water per minute and from 0.7 to 0.8 kilos. dry ore per minute; Embrey vanner, 1.5 inches per foot slope, 80 inches per minute travel of belt, 240 vibrations of 0.5 inch per minute.

The mill is a little 3-stamp Fraser and Chalmers prospecting mill of 1882. It is very satisfactory in all respects except the number of stamps. A school battery should have either two or five stamps; the former is preferred by us. Three stamps cannot have an order of drop which satisfactorily distributes the sand.

The vanner is a standard 4-foot Frue, made by Fraser and Chalmers in 1882. It is a very good one, the belt being today as good as new. It is run from five to ten days in a year.

The canvas table is supplied with an accurate distributer. The canvas is No. 6 cotton duck, with the warp laid across the table for the greatest roughness, and is cut from a roll woven 10 feet wide. The feed water is the quantity, and the pulp is two to three times the quantity used by the Gates canvas plant. The copper plate is $\frac{1}{8}$ inch thick, of softest copper.

The amalgam is made by dissolving 95 grammes of silver in 380 c.c. of nitric acid (1.2 sp. gr.), with addition of 817 c.c. of water after solu-

tion. Pure mercury is then added at the rate of 16 parts of mercury to 1 part of silver. It should be stirred at short intervals during the formation of the amalgam. The result is a soft amalgam, clean and free from crystals or mercurous nitrate. Failure to follow this rule exactly is liable to give a very impure amalgam, which will require time and trouble to clean.

The apron plate is cleaned preparatory to the application of silver amalgam as follows: it is washed off with water, scoured with wet infusorial earth or very fine sand, and then washed off with water again. Obstinate black spots can be removed by scouring with a flat piece of pumice stone and water, adding mercury to plate the cleaned copper. It is then washed all over with a strong solution of cyanide, adding mercury, again rinsed off with water, and then rubbed dry with clean cloth or cotton waste which must be free from oil. A moderate quantity of mercury is now rubbed on without water, after which the plate is ready for the amalgam. No water is allowed upon it yet.

The clean amalgam is squeezed in chamois skin to a moderately hard ball, and rubbed without water on the clean, bright, amalgamated copper surface of the apron plate. (A flat, bristle paste brush may be useful to obtain an even distribution.) This coating is quick to catch gold, and prevents the gold from coming in contact with the copper. No water is allowed upon it until stamping begins.

After the run, the plate is rinsed off with water, and the amalgam scraped off as clean as possible with a rubber scraper. More mercury is rubbed on, and the plate is again scraped. This is repeated twice more, and all the amalgam is put together. If there is any hard amalgam which has not been removed, it is gently rubbed with a flat piece of pumice stone in the presence of water and mercury, and so removed without injury to the plate. The amalgam from the plate, combined with that from the traps, is retorted; the residue is melted with borax in a crucible, and the bullion is parted for gold.

The battery residue is worked up, as shown in the tree of the process, yielding amalgam, Wilfley heads, coarse tailings, and fine tailings, which are added to the main portions of these products.

Since the battery is fed with pure mercury, while the apron plate is coated with silver amalgam, the battery amalgam enables us to get a valuation on the fineness of the gold caught at this point. We have no means to get this ratio on the portion of the gold caught on the apron plate.

The mercurous nitrate and a little residual silver nitrate from making silver amalgam are worked over for mercury and silver by immersing strips of iron in the liquid, which precipitates the metals as amalgam.

The results of seven tests are given here.

ORE NO. 2,423, FROM NOVA SCOTIA, NOVEMBER 12, 1901. CLASS WORK.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent. of the Total Gold in Crude Ore.
Ore fed	384.8	1.03	0.003531	13.5873	. .
Products:					
Battery and ball-mill gold	. .	. .	. . .	14.1545	87.40
Plate and trap gold	. .	. .	. . .	0.6786	4.19
Vanner and Wilfley heads	19.9	0.84	0.002868	0.5708	3.53
Vanner and Wilfley coarse tailings	225.2	0.06	0.000213	0.4794	2.96
Vanner and Wilfley fine tailings	139.0	0.06	0.000206	0.2860	1.77
Unaccounted for	0.7	*1.03	0.003531	0.0247	0.15
Total	384.8	. .	. . .	16.1940	100.00

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	91.59
Per cent. of gold contents in vanner concentrates . . .	3.53
Total	95.12
	Oz. per ton.
Assay by fire	1.03
Assay based on mill run	1.23

ORE NO. 2,425, FROM NOVA SCOTIA, NOVEMBER 19, 1901. CLASS WORK.

	WEIGHT, KILOS.	ASSAY, OZ. PER TON.	GOLD, PER CENT.	GOLD, GRAMMES.	PER CENT. OF THE TOTAL GOLD IN CRUDE ORE.
Ore fed	266.1	0.06	0.0002057	0.5475	. .
Products:					
Battery and ball-mill gold	. .	. .	. . .	0.03966	5.40
Plate and trap gold	. .	. .	. . .	0.27700	37.72
Vanner and Wilfley heads	11.6	0.06	0.0001936	0.02246	3.06
Vanner and Wilfley coarse tailings	178.9	0.05	0.0001695	0.30326	41.34
Vanner and Wilfley fine tailings	62.1	0.03	0.0001628	0.06387	8.70
Unaccounted for	13.5	*0.06	0.0002057	0.02777	3.78
Total	266.1	. .	. . .	0.73402	100.00

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	43.12
Per cent. of gold contents in vanner concentrates . . .	3.06
Total	46.18
	Oz. per ton.
Assay by fire	0.06
Assay based on mill run	0.08

ORE NO. 2,444, FROM NOVA SCOTIA, NOVEMBER 4, 1902. CLASS WORK.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent. of the Total Gold in Crude Ore.
Ore fed	298.2	0.16	0.0005486	1.636	. .
Products:					
Battery and ball-mill gold	. .	. .	. . .	2.0300	78.43
Plate and trap gold	. .	. .	. . .	0.1481	5.72
Vanner and Wilfley heads	13.8	0.42	0.001440	0.1987	7.68
Vanner and Wilfley coarse tailings	186.7	0.02	0.00006857	0.1280	4.94
Vanner and Wilfley fine tailings	81.6	0.025	0.00008570	0.0699	2.70
Unaccounted for	16.1	*0.025	0.00008570	0.0138	0.53
Total	298.2	. .	. . .	2.5885	100.00

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	84.15
Per cent. of gold contents in vanner concentrates . . .	7.68
Total	91.83
	Oz. per ton.
Assay by fire	0.16
Assay based on mill run	0.253

ORE NO. 2,444, FROM NOVA SCOTIA, NOVEMBER 11, 1902. CLASS WORK.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent. of the Total Gold in Crude Ore.
Ore fed	338.8	0.15	0.0005142	1.742	. .
Products:					
Battery and ball-mill gold	. .	. .	. . .	1.9969	75.16
Plate and trap gold	. .	. .	. . .	0.2022	7.61
Vanner and Wilfley heads	15.0	0.42	0.001440	0.2160	8.12
Vanner and Wilfley coarse tailings	205.2	0.02	0.00006857	0.1407	5.29
Vanner and Wilfley fine tailings	107.4	0.025	0.00008570	0.0921	3.46
Unaccounted for	11.2	*0.025	0.00008570	0.0096	0.36
Total	338.8	. .	. . .	2.6575	100.00

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	82.77
Per cent. of gold contents in vanner concentrates . . .	8.12
Total	90.89
	Oz. per ton.
Assay by fire	0.15
Assay based on mill run	0.229

ORE NO. 2,444, FROM NOVA SCOTIA, NOVEMBER 18, 1902. CLASS WORK.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent. of the Total Gold in Crude Ore.
Ore fed	332.6	0.25	0.0008570	2.850	. .
Products:					
Battery and ball-mill gold	. .	. .	. . .	1.9820	76.44
Plate and trap gold	. .	. .	. . .	0.0850	3.28
Vanner and Wilfley heads	12.9	0.40	0.001373	0.1769	6.82
Vanner and Wilfley coarse tailings	201.2	0.03	0.0001028	0.2069	7.98
Vanner and Wilfley fine tailings	114.1	0.035	0.0001200	0.1370	5.28
Unaccounted for	4.4	*0.035	0.0001200	0.0053	0.20
Total	332.6	. .	. . .	2.5931	100.00

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	79.72
Per cent. of gold contents in vanner concentrates . . .	6.82
Total	86.54

	Oz. per ton
Assay by fire	0.25
Assay based on mill run	0.227

ORE NO. 2,444, FROM NOVA SCOTIA, FEBRUARY, 1902. THESIS OF C. H. BURR AND B. E. MCKECHNIE.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent. of the Total Gold in Crude Ore.
Ore fed	356.2	0.13	. . .	. .	. .
Products:					
Battery gold	. .	. .	. . .	2.01902	72.58
Plate gold	. .	. .	. . .	0.22736	8.17
Vanner heads	16.8	0.44	0.001511	0.25380	9.39
Vanner coarse tailings	208.6	0.02	0.00007401	0.15444	5.54
Vanner fine tailings	122.3	0.03	0.00009900	0.12107	4.35
Unaccounted for	8.5	*0.02	0.00007	0.00566	0.20
Total	356.2	. .	. . .	2.78135	100.18

* Assay assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	80.70
Per cent. of gold contents in vanner concentrates . . .	9.39
Total	90.09

	Oz. per ton.
Assay of ore by fire	0.13
Assay based on mill run	0.222

ORE NO. 2,361, FROM NOVA SCOTIA, MARCH, 1901. THESIS OF HENRY C. MARCUS.

	Weight, Kilos.	Assay, Oz. per Ton.	Gold, Per Cent.	Gold, Grammes.	Per Cent of the Total Gold in Crude Ore.
Ore fed	256.30	0.13	0.000444	1.13797	. .
Products:					
Battery gold	. .	. .	. . .	2.38216	74.84
Plate gold	. .	. .	. . .	0.51440	16.16
Vanner heads	15.65	0.11	0.000377	0.05904	1.86
Vanner coarse tailings	195.85	0.02	0.000069	0.13156	4.13
Vanner fine tailings	43.45	0.057	0.000195	0.08493	2.67
Unaccounted for	5.35	*0.057	0.000195	0.01043	0.33
Total	256.30	. .	. . .	3.18252	99.99

* Assumed for purposes of calculation.

Per cent. of gold contents saved by amalgamation . . .	91.00
Per cent. of gold contents in vanner heads	1.86
Total	92.86
	Oz. per ton.
Assay of ore by fire	0.13
Assay based on mill run	0.36

SUMMARY OF THE END RESULTS OF THE SEVEN TESTS.

Ore Number.	Percentage of Gold in Crude Ore.						Assay by Fire, Oz. per Ton.	Assay by Mill Test, Oz. per Ton.
	Battery and ball mill.	Plate and trap.	Vanner and Wilfley heads.	Vanner and Wilfley coarse tailings.	Vanner and Wilfley fine tailings.	Unaccounted for.		
2,423	87.40	4.19	3.53	2.96	1.77	0.15	1.03	1.23
2,425	5.40	37.72	3.06	41.34	8.70	3.78	0.06	0.08
2,444	78.43	5.72	7.68	4.94	2.70	0.53	0.16	0.253
2,444	75.16	7.61	8.12	5.29	3.46	0.36	0.15	0.229
2,444	76.44	3.28	6.82	7.98	5.28	0.20	0.25	0.227
2,444	72.53	8.17	9.39	5.54	4.35	0.20	0.13	0.222
2,361	74.84	16.16	1.86	4.13	2.67	0.33	0.13	0.36

Attention is called to the slight variation in the mill assay of the four tests on No. 2,444, and also to the considerable variation in the assays by fire.

Remarks. — The method here used in tabulating the results of a test has been found to be a most concise and satisfactory one. As the value of the ore obtained by the mill run is much more accurate than that based on the assay of the ore, the percentages found in the column headed "Per cent. of the total gold" are based on the total gold in the ore as found by the mill run, and not on the assay of the feed; in fact, one of the objects of this work is to show the student the impossibility of valuing a free-milling gold ore by sampling and assaying.

The degree of accuracy attained here is, we believe, up to that of the very best mill practice. It has been attained by locating the causes of error, and then by removing them as completely as possible, even by departing, if necessary, from large-scale mill methods.

THE WATER SUPPLIES OF SOUTHEASTERN ALASKA.

By ELLEN H. RICHARDS.

Two considerations led me to take the portable laboratory [1] with me on the long journey: first, that its use might be tested under very different conditions from those under which the Mexican water supplies were examined;[2] and second, because a record of the condition of the available waters in this early stage of the development of the country must have a certain value in the future.

The tables may seem to be meagre in comparison with those which are made from the testing of gallon samples in a fully equipped laboratory, but it is believed that a good idea may be obtained of the general character of the waters on the given date.

At present there are no "wells," as the term is generally applied, in the coast towns visited. In all the localities where there is anything approaching level ground there has accumulated from the luxuriant vegetation rich black peaty soil of great depth; a thickness of 5 to 15 feet is common.

In the rainy season this holds water like a sponge, so that hollows scooped out 4 or 5 feet deep, with sides supported by a rough wooden curb or left sloping inwards, readily fill with water, which collects again as it is dipped out.

These pools serve the Indians for the scanty supply they use, and as they are dug on the hillside at some distance from the houses, which are huddled together on the shore, there does not seem great danger from contamination other than from unclean vessels and hands used in dipping up the water.

The 25th of July was toward the end of the dry season, and the pools were dry or very low, although the vegetation was rank and vigorous.

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[1] Technology Quarterly, Vol. XIV, p. 295.

[2] *Transactions*, A. I. M. E., Mexican meeting, Nov., 1901.

This black water is quite a feature of the country. In the vicinity of Sitka, for instance, where it has collected in lakelets as black as ink; indeed, containing iron and tannin, it is one variety of ink. The white population do not use this water (one of the ship's officers said, "The water is poison all along this coast"), but depend very largely upon cisterns, which in that climate seem to furnish abundance of good water. Large tanks having a capacity of 200 barrels and more are frequently found, and furnish water for baths and laundry purposes in small places like Fort Wrangell, where the little stream brought from the mountains for the use of the sawmill is highly charged with iron.

At the Indian village of Killisnoo, situated on an island where the fish-oil factory is in operation only part of the year, instead of collecting the rainfall, the engineer of the factory brings water in a scow from a creek on the mainland, and allows the inhabitants to use it from the tap in the works, otherwise they depend on the dug pits. Judging from the all-pervading odor, it is probable that cistern water would absorb the odor from the factory to a decided degree. This water was the only sample obtained on the trip which gave high results in chlorine and ammonia.

Most of the towns are able to utilize mountain streams; sometimes these are really of glacial water, which many persons consider dangerous for drinking.

At Juneau some further provision must be made if it is to realize its ambition and become the capital of Alaska, since the use of the streams for hydraulic work is liable to interfere with the present good quality. Even now it runs so turbid that it is filtered through a bank of sand before entering the pipes.

On Douglas Island, opposite Juneau, $1,000,000 have been spent in cutting a trench fifteen miles long, intercepting springs and streams in order to obtain a sufficient supply for the Alaska-Treadwell mills for eight months in the year. Therefore this should be a typical sample.

At Ketchican, as at many places in the far north, the only supply in winter comes from melted snow.

Sitka has a heavy rainfall, 60 to 95 inches annually, and is well supplied with cisterns, large and small. The sample Number 17 in the table was taken from the large cistern of the United States Agricultural Experiment Station, which furnishes the house with hot and cold water. The station occupies the site of the old Castle Baranoff, on an eminence nearly surrounded by water.

Indian River is a stream of good volume, clear and cold, running in a shallow layer over pebbles about half a mile back from the town, from which drinking water for a large portion of the inhabitants is hauled in barrels, or in the same square oil cans used in Mexico. It was delicious to the taste. This stream was said to have "mineral" in it, and was preferred to the cistern water. The analysis does not seem to bear out this statement. It may be that in times of high water some taste is perceived, but the mineral content is low. This stream could be utilized for a town supply, if the demand was sufficient for the installation of water works.

The nearest to an ideal supply and the most intelligent use of it is at Skagway, where a lake of considerable area — Lake Dewey — gives an abundant quantity of excellent quality. A reservoir was built in 1898 in a depression in the mountain cliff far above the town, where the water is stored, and from which it is distributed under the high pressure due to the elevation of the reservoir.

It was gratifying to find a considerable knowledge of the sources and character of the various waters even among the common people. This may be because so many of them are from the Puget Sound region, where remarkable intelligence is shown in securing safe water. Seattle and Portland are in strong contrast with San Francisco and many cities in the Middle West, as well as in the East, where it is difficult to secure appropriations for water works. At Missoula, Montana, for instance, we were told by a waitress that the town supply came from Rattlesnake Creek, was stored in a reservoir, and that it was the purest in the state. Many more highly educated people in the East are ignorant of the source and quality of the drinking water.

Typhoid fever is almost unknown in Seattle, which obtains water from Cedar River, thirty miles from the city. The water is stored in reservoirs, and is called by the citizens "the finest in the country."

A question of great interest is, does the rule of normal chlorine hold on the Pacific coast as on the Atlantic and in Mexico?

In order to give an approximate answer, samples were carefully collected from typical stations and taken to Berkeley, California, where the determinations were made through the courtesy of the authorities of the university. My thanks are due to Professors Hilgard, Jaffa, and Colby for the facilities so kindly placed at my disposal.

In so far as conclusions may be reached by the results on single samples, it would seem that we may rely on limits previously set,

Analysis of Alaskan Waters.

(Parts in 1,000,000.)

Number.	Locality.	Date of		Physical.			Total Residue on Evaporation.	Nitrogen as			Hardness.	Chlorine.	Iron.
		Collection.	Examination.	Color (Massachusetts standard).	Turbidity.	Sediment.		Free ammonia.	Nitrites.	Nitrates.			
1	Ketchican town supply	1903 July 23	1903 July 24	.05	0	0	. .	0	0	0	0.0	1.95	. .
2	Ketchican cistern	"	"	.50	Very slight	0	. .	.050	0	0	16.9	1.77	. .
3	Fort Wrangel Pool	24	"	1.0	0	0	. .	.030	0	0	16.9	. .	000
4	Fort Wrangel large cistern	"	"	1.8	Slight	0	. .	.010	0	0	11.1	1.16	. .
5	Fort Wrangel supply from hills to sawmill and town	"	"	1.5	0	0	. .	.030	0	0	1.6	1.23	.200
6	A sizable stream at Tonka cannery	"	"	0.2	0	0	. .	0	0	0	14.3	0.80	.020
7	Juneau town supply	"	25	0.01	0	0	47.8	0	0	0	62.9	0.85	. .
8	Douglas Island, Alaska-Treadwell supply	28	28	.10	Slight	Slight	41.2	0	0	.010	11.5	1.39	000
9	Lake Dewey, supply of Skagway, 1898 Res.	25	26	.08	0	0	. .	0	0	0	14.3	0.92	. .
10	White Pass R.R., large falls	"	"	. .	. .	. .	. .	. .	. .	. .	. .	0.59	. .
11	White Pass R.R., small stream from mountains	"	"	.02	0	0	. .	0	0	0	7.9	. .	. .
12	Tank in White Pass Station from stream near boundary	"	"	.03	Slight	0	. .	.030	0	0	7.9	. .	. .
13	Head waters of Yukon River	"	"	.10	Distinct	Slight	. .	.030	0	0	1.6	. .	. .
14	Stream from Davidson Glacier	"	"	Too turbid	Distinctly milky	Clayey	. .	0	0	0	11.5	0.40	. .
15	Killisnoo	26	27	0.7	Slight	Slight	. .	.700	.005	.050	112.0	Very heavy Pr.	
16	Indian River, Sitka	27	"	0.0	None	Very slight	21.4	.010	0	0	14.3	3.3	. .
17	Cistern, Agricultural Station, Sitka	"	"	0.3	Slight	Slight	. .	.040	.001	.080	8.3	3.9	. .

namely, that beyond 75 to 100 miles from a rocky shore the normal chlorine never exceeds 1.00 part per million, and on the other hand that it is never entirely absent, falling to .4 or .6 only.

A glance at the map will show that Juneau and Skagway are just about one hundred miles from the open ocean, that there is no breaking of the waves on rocks such as to drive spray high in the air nearer than fifty miles at White Pass, while Fort Wrangell and Ketchican are more exposed on the south to the open sea in Dixon's Entrance. Douglas Island, surrounded by salt water, gives only 1.39 parts of chlorine, and this, as has been shown, is a typical sample of mixed water approaching a yearly normal.

Davidson Glacier is the eastern portion of the Muir and, therefore, is not exposed to the winds from the Pacific shore of the island, and may be considered to show the residual chlorine in the air sweeping over the entire country, as in our own Adirondacks and western slopes of the White Mountains.

At Sitka, on the other hand, surrounded by the ocean, within a few miles of the dashing waves, the chlorine content of the water is even higher than in the waters of the sand-surrounded Nantucket and Martha's Vineyard. It may be noted here that the waters supplying the cities of Seattle, Spokane, and Walla Walla show 1.50 parts per million, according to Professor Byers, of the State University.

As bearing on the question of the interpretation of the significance of nitrites and nitrates in water, it is to be noted that they are generally absent in the waters from these primeval hills, rich in vegetation as they are. Even the black water from the thick peat failed to yield nitrates, which are so abundant in the black prairie soil of Illinois, once the home of the buffalo. Possibly this may indicate a necessity for inoculation with nitrifying organisms before agriculture will be successful.

The absence of nitrites, even in samples showing ammonia, may also be due to absence of animal contamination.

On the whole the country seems to be well provided with good soft water fairly accessible. It is to be hoped that medical men will make careful record of the effects noticed from the use both of the glacial waters and the peaty waters, so that the question of their harmfulness may be settled.

NOTES ON THE WATER SUPPLIES IN THE BLACK HILLS OF SOUTH DAKOTA AND VICINITY.

By ELLEN H. RICHARDS.

Too often the first settlers, whether they are pioneer agriculturists or miners, neglect ordinary precautions as to the purity of the drinking water. Through this neglect the sources become polluted, epidemics follow, and not until some strong pressure is put upon them do either class apply the necessary remedy. When a mining company has lost a few of its most valued men by fever it begins to think it more economical to bring in safe water, even at considerable expense. The company is, to its credit, usually generous to the community when once it has introduced the good water. There are discouragements in changing the habits of a frontier town if once they have depended on wells. The ordinary workman does not take much stock in sanitary theories; because the glass of water does not take effect as quickly as the bullet, he scoffs at danger, and his family fall victims to his ignorance. Criminal indifference occurs higher in the scale. At one hotel, kept with decided carefulness in most respects, a certain spring water was advertised to be exclusively used on the table. One day the cart failed to go to the spring, and the town supply, dangerous in quality, was substituted, apparently unnoticed by most of the guests.

Education all along the line is needed, although the railroad companies take much better care of the water supplied to the dining cars than was the case a few years since.

No better work can be undertaken by any state board of health than a sanitary survey of the waters of the state, the results to be published widely. The addition to information of a geological significance would be considerable; for instance, in Spearfish cañon the layers of white rock are called gypsum, but none of the waters in that valley show sulphates.

In the semi-arid regions this examination is increasingly important, especially because a study of peculiarities is needed to help in the interpretation of the results both before and after the use of water for

irrigation purposes. If this knowledge is not obtained, some serious results may follow the re-use of irrigation water.

For instance, in the case of the spring water brought to Edgemont (see table), what is the significance of the high nitrates? Do they indicate an old buffalo range, or was this spring a favorite resort for the Indians? Or is there a cause in present surroundings?

The contemporaneous presence of ammonia and nitrites would seem to indicate the latter, and to demand an examination of conditions, even though a condemnation of this source would mean bringing in by train water from several score of miles.

An instructive set of results is given by the samples from Deadwood and Lead. The stream, coming originally from the hills, has been used for several mining and milling operations, and the presence of ammonia and nitrites indicates a degree of contamination. The precipitous and rocky bed gives no chance for the formation of nitrates in quantity; the constant addition of organic matter reduces them if they are formed. The typhoid rate is high among those who do not boil the water. The cemetery of the town is situated on the one approximately level spot, on a cliff of some 400 feet elevation above the town, and is a favorite resort on account of the view. From a crevice in this cliff about 50 feet above the street there issues a copious stream of clear, cold water, much prized by the inhabitants. It is named White Rock in the table. This shows the greatest previous pollution of any sample secured. The special spring in the town of Lead also indicates a similar pollution.

A further confirmation of the value of nitrates as an indication is seen in the set from Sylvan Lake, which is in granite rock in the region of Harney's Peak. It is soft surface water, confined within its walls only three years ago, and resembles our Eastern waters. The clear, cold spring near it is evidently beginning to feel the presence of the cottages and the stable above it, while the stream at the watering place is the typical water of the South Black Hills, like that which supplies the town of Custer. The well used by the railroad did not give so good an account of itself, showing nitrites and chlorine. An investigation revealed large cattle yards and several houses near by.

Another interesting sample is the Giant Spring at Great Falls, Montana. This large body of water boils up in the very edge of the Missouri River. Its source is unknown, but must be many miles distant. It is a hard water, but shows no nitrates, although sulphates

South Dakota Waters.

(Parts in 1,000,000.)

Locality.	Date of		Physical.			Nitrogen as			SO_3.	Hardness.	Chlorine.
	Collection.	Examination.	Color (Massachusetts standard).	Turbidity.	Sediment.	Free ammonia.	Nitrites.	Nitrates.			
	1903	1903									
Kidney Spring, Deadwood	June 19	June 20	0	0	0	0	0	0	Considerable	196.0	Faint
White Rock Spring, Deadwood	"	"	0	0	0	0	0	7.000	Distinct	260.7	Heavy
Spring from other side of White Rock Hill, Deadwood	"	"	0	0	0	0	0	.400	Slight	. .	Slight
Stream. Town supply, Deadwood	"	"	Dark turbid	Decided	Considerable	.050	.006	0	. .	164.0	No turbidity
Supply, Lead	22	"	0	0	0	. .	0	0	. .	295.0	Very slight
Special spring, Lead	"	"	0	0	0	. .	.002	4.000	. .	. .	Heavy
Little Spearfish River at Falls	23	23	0	0	0	. .	0	0	No turbidity	238.0	No turbidity
Spearfish River at town	"	"	0	0	0	. .	0	0	"	245.0	"
Fountain in hotel at Spearfish from spring	"	"	0	0	0	. .	0	0	"	260.7	"
Sylvan Lake	24	24	.1	0	Slight	.050	0	0	"	24.7	"
Spring under rock near entrance to Sylvan Lake	"	"	0	0	0	.010	0	.200	"	22.1	Slight
Watering place on the road from Custer	"	"	0	0	0	0	0	0	"	14.3	No turbidity
Burlington and Missouri R.R. wells at Edgemont *	25	25	0	0	Slight	.300	.040	.400	Heavy	148.4	Heavy
Spring water hauled from the hills for the town and hotel drinking water	"	"	0	0	0	.150	.025	5.000	Distinct	228.2	Distinct

* Alkali water; cattle drink it with reluctance.

abound and chlorine is present (an examination made in 1898 gave 4.5 parts of chlorine, .100 parts of nitrate, and 316 parts of hardness per million).

In lead ore districts, of which the Cœur d'Alene, Idaho, is an example, the mineral formation complicates the problem, and distilling the drinking water seems the only way to be certain of its safety, if for no other reason, because the excessive amount of iron is objectionable.

Spokane is fortunate in one way in having Cœur d'Alene Lake as its reservoir, but since the lake is already well seeded with Anabœna, it is sure to have trouble sooner or later; indeed, these soft waters, if stored in the bright sunlight in the midst of the dusty plains, are very inviting feeding grounds for many water plants. One of the coming problems is, then, the exclusion of all such as give odors and tastes from the very inception of the works.

NOTES ON THE METALLURGY OF COPPER OF MONTANA.[1]

By H. O. HOFMAN.

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[1] Reprinted from *Transactions of the American Institute of Mining Engineers*, Albany meeting, February, 1903.

I. Introductory.

In 1901[1] this country produced 268,782 long tons of fine copper. Of this total, Montana is credited with 102,621 long tons, or 38.2 per cent.

The leading smelting works are located in Butte, Anaconda, and Great Falls. In Butte are the works of the Colorado Smelting and Mining Company, the Colusa Smelter of the Montana Copper Company (closed in 1893), the plant of the Parrot Silver and Copper Company (closed in 1899), the old Bell plant (closed in 1884), the Clark's Colusa (closed in 1893); then come the active works of the Colusa Parrot Mining and Smelting Company (Butte Reduction Works), the Butte and Boston Consolidated Mining Company, and the Montana Ore-Purchasing Company.

In Anaconda are the old and new (Washoe) works of the Anaconda Copper Mining Company; in Great Falls the establishment of the Boston and Montana Consolidated Copper and Silver Mining Company.

The active works furnished in 1901, approximately, the following amounts:

Anaconda Copper Mining Company	113,800,000	pounds.
Boston and Montana Consolidated Copper and Silver Mining Company	54,700,000	"
Montana Ore-Purchasing Company	29,900,000	"
Butte and Boston Consolidated Mining Company	22,200,000	"
Butte Reduction Works	18,000,000	"
Colorado Smelting and Mining Company	7,500,000	"
	246,100,000	"

The discrepancy of 17,000,000 pounds of copper between the figures of production is due to the fact that the matte of some works is converted in others, and that both are credited with the copper they turned out.

II Condensed Account of Past and Present Plants.

Colorado Smelting and Mining Company. — Started 1879 by the late Henry Williams.[2] The ore was roasted at first in the long-hearth

[1] *United States Geological Survey*, Mineral Resources, 1901, p. 160.

[2] R. W. Raymond, *Engineering and Mining Journal*, July 19, 1902; J. Douglas, *The Mineral Industry*, IV, p. 283; C. W. Goodale, *International Mining Congress*, Butte, 1902.

hand reverberatory furnace, having a hearth 12 by 50 feet, and then smelted in a reverberatory matting furnace, with hearth 14 feet 7 inches by 9 feet, wood being used as fuel. The original smelting furnaces treated 12 tons of ore in twenty-four hours, producing matte assaying 60 per cent. copper and from 700 to 800 ounces silver to the ton, which had to be hauled 200 miles to reach the railroad. In 1889 Brückner cylinders came into use for roasting ores, followed in 1892 by the R. Pearce single-deck turret furnace. In 1894 R. Pearce's first double-deck turret furnace was added, and in 1901 the first six-deck turret furnace of R. F. Pearce was put in operation. At present (summer, 1902) the roasting department has four single-deck turret furnaces with 6-foot hearths, five double-deck turret furnaces (one with a 6-foot and four with a 7-foot hearth), and one six-deck turret furnace with a 7-foot hearth.

The hearths of the reverberatory matting furnaces were made 21 by 12 feet in 1889, increasing the above capacity to 18 tons in twenty-four hours. At present there are three matting reverberatories with hearths 47 by 20 feet (the first of these larger furnaces having been erected in 1899). The matte containing copper from 50 to 55 per cent., silver, 100 ounces, and gold, 1.5 ounces to the ton is sold.

Colusa Smelter of the Montana Copper Company. — Started 1880 by A. Wartenweiler, with four long hand reverberatories for roasting (hearths 60 feet by 11 feet 6 inches), and two reverberatory matting furnaces (hearths 15 feet 9 inches by 10 feet). Smelting begun 1881; a reverberatory matting furnace treated in twenty-four hours 12 tons of raw and roasted ores, producing 65-per cent. copper matte, with a consumption of ten cords of wood. Lump ore was at first heap-roasted, but, stopped on account of the smoke nuisance, was replaced in 1882 by stalls.[1] In 1884[2] there were in operation, besides the stalls, twelve long-hearth hand reverberatory roasting, six reverberatory matting, and one blast furnace. The latter, 3 feet by 4 feet 6 inches at the tuyères and 10 feet high, was run with charcoal. Works sold 1888 to the Boston and Montana Consolidated Copper and Silver Mining Company, and formed the so-called Upper Works. They closed down in 1893 when the new Great Falls establishment of the company made them superfluous.

[1] *Mineral Resources of the United States*, 1891, p. 94.

[2] *Mineral Resources of the United States*, 1883–84, p. 339.

Parrot Silver and Copper Company.—Started July, 1881. Ore was at first roasted in eleven long hand reverberatories (hearths 60 by 14 feet) and smelted in six matting reverberatories (hearths 14 feet by 11 feet 6 inches). Weight of smelting charge, 2 to 3 tons; 10 tons put through a furnace in twenty-four hours. Matte (60 to 67 per cent. copper and 40 to 45 ounces silver per ton) at first brought forward to blister copper, but this soon given up on account of the excessive cost and the fact that matte was more easily marketed than blister copper. Shortly after starting of works, a stall 40 feet deep and 9 feet high[1] was built by J. T. Reese to roast lump ore. It proved a failure, and was replaced by A. J. Schumacher with open stalls 8 feet deep, 6 feet high, and 6 feet wide.[2] In 1891 there were in operation 120 stalls.[3] The hand reverberatory roasting furnaces were supplemented, 1889, by two small Spence mechanical shelf-roasting furnaces,[4] each treating 5 tons of concentrates in twenty-four hours, reducing sulphur to from 6 to 7 per cent.; these were replaced in 1892 by a round and in 1893 by two oblong Keller-Gaylor-Cole mechanical shelf burners.[5]

A Roberts four-hearth mechanical reverberatory roaster, made by the Western Iron Works, of Butte, and similar to the Wethey furnace,[6] was put in operation 1897. Hearths of matting reverberatories enlarged in 1887 to 16 feet by 12 feet 6 inches. For lack of space they never reached the large sizes of the other furnaces at Butte. The largest furnace, 1895, had a hearth of 22 feet by 16 feet. In 1884 a Herreshoff 48-inch water-jacket blast furnace was erected by E. D. Peters; in 1885 a 3- by 6-foot blast furnace, with cast-iron water jackets, was added, but was soon replaced by A. J. Schumacher with a 3- by 8-foot furnace having steel jackets. In 1884 the converting of copper matte was begun under the general direction of the inventor of the process, Pierre Manhès. The practice was to melt 40- to 50-per cent. copper matte in a cupola furnace, tap it into converter, blow to white metal, and pour; then melt the white metal in the cupola, and blow it to blister copper in the converter. In 1885 A. J. Schumacher

[1] Width unknown.

[2] E. D. Peters, *Mineral Resources of the United States*, 1883–84, p. 389; also *Modern Copper Smelting*, 1895, p. 181.

[3] *Mineral Resources of the United States*, 1891, p. 981.

[4] Peters, *Modern Copper Smelting*, 1895, p. 220.

[5] Peters, *op. cit.*, p. 214; Hofman, *Metallurgy of Lead*, 1899, p. 191.

[6] Hofman, *op. cit.*, 1899, p. 195; *The Mineral Industry*, 1898, VI, p. 449.

succeeded in making metallic copper from 40- to 50- per cent. matte in one operation of two consecutive stages, and thus laid the foundation of the modern practice of converting.

When the works were closed down August 20, 1899, the roasting department contained two Keller-Cole-Gaylord furnaces, each having a capacity of 50 tons ore, and one O'Hara furnace, treating 50 tons in twenty-four hours. Smelting was carried on in three undergrate-blast reverberatory furnaces with hearths 20 by 12 feet, treating altogether 135 tons of ore in twenty-four hours, and in two blast furnaces 44 inches by 96 inches at the tuyères, each putting through daily 120 tons of charge. The converting department had six upright converters 5 feet in diameter and 8 feet 6 inches in total height.

Bell Plant. — Soon after the erection of the Parrot works followed the building of the Bell plant, which roasted in long-hearth reverberatories and smelted in blast furnaces. In 1885[1] it had two hand roasters and two blast furnaces.

Clark's Colusa. — Built 1884 by W. A. Clark; sold 1888 to Boston and Montana Company, and formed its Lower Works; closed 1893 in favor of the new plant at Great Falls. At this plant the first two-hearth mechanical O'Hara roasting furnace was operated, 1885; the hearths were 50 by 7 feet. A second O'Hara furnace, erected 1885,[2] had hearths 70 by 7 feet, and treated 30 tons ore in twenty-four hours. In 1891[3] ores were roasted in three O'Hara furnaces and one 10-ton Brückner cylinder. The first smelting furnace, a circular water-jacket blast furnace, 36 inches in diameter at the tuyères and 9 feet high, was replaced 1885 by a larger furnace. In 1887 two 50-ton circular water-jacket blast furnaces were put in operation. In 1886 two reverberatory matting furnaces were added to the plant, each treating 12 tons of charge in twenty-four hours.

Colusa-Parrot Mining and Smelting Company's Plant (Butte Reduction Works). — Started 1885 by employees of the Parrot Smelter. At first ore was roasted in heaps and then smelted (45 tons in twenty-four hours) in a 36-inch water-jacket blast furnace. A long hand reverberatory (hearth 100 by 14 feet), erected 1886, remained in operation until 1888, when it was cut in two, making two furnaces 50 by 14 feet each. In the same year the first Brückner furnace was installed (cylinder 15

[1] *Mineral Resources of the United States*, 1885, p. 216.

[2] *Mineral Resources of the United States*, 1885, p. 216.

[3] *Mineral Resources of the United States*, 1891, p. 94.

by 7 feet, charge 7 tons); in the fall of 1889 a second cylinder, 20 by 8 feet. In 1894 the first four-deck Wethey calciner was built, replacing one of the 50- by 14-foot hand reverberatory roasters and the 15- by 7-foot Brückner cylinder. Its work proving satisfactory, a second Wethey furnace was erected. The 50- by 14-foot hand roaster was replaced by a larger furnace, 75 by 5 feet, to be used mainly for roasting slimes. In 1898 the third and in 1900 the fourth Wethey furnace was installed, replacing the remaining hand roaster and Brückner cylinder. Smelting capacity of the plant increased, 1886, by erection of a 96- by 42-inch Orford brick furnace; the original 36-inch furnace put out of blast and replaced in 1889 by one of 38 inches at tuyères. In 1897 a sectional blast furnace of the United Verde Hot-Air type, 84 by 42 inches at tuyères, replaced the two older furnaces. In 1900 a second rectangular furnace, 112 by 42 inches at tuyères, was put in blast, and in 1901 the 84- by 42-inch furnace was enlarged to 112 by 42 inches.

First reverberatory matting furnace (hearth 15 by 9 feet) erected 1887; the second (hearth 18 by 11 feet), treating from 12 to 15 tons in twenty-four hours, erected 1888. It was then customary to wet down roasted ore, and shovel it into matting furnace through side doors. In 1889 hoppers placed over the furnaces, and roasted ore charged hot through the roof. This increased smelting capacity from 18 to 21 tons in twenty-four hours. In 1896 a large reverberatory matting furnace (hearth 35 by 16 feet, capacity 45 to 50 tons ore in twenty-four hours) replaced the two smaller furnaces. A second (hearth 45 by 16 feet, capacity 55 to 70 tons) was built in 1897; and in 1900 a third (hearth 50 by 20 feet, capacity 85 to 100 tons). This last did so well that the 1896-furnace was rebuilt on the lines of the furnace of 1900. Present plant: four Wethey four-deck calciners, two water-jacketed blast furnaces (112 by 42 inches at tuyères), and three reverberatory matting furnaces (hearths 45 by 16, 50 by 20, and 50 by 20 feet).

Butte and Boston Consolidated Mining Company. — Smelting works started 1885 with four Brückner cylinders (8 by 18 feet), two reverberatory matting furnaces (hearths 22 by 17 feet, treating 5-ton charges), and two blast furnaces, the larger being 96 by 36 inches at the tuyères and 11 feet high. In 1889 two O'Hara roasting furnaces were added; later, four Allen-Brown-O'Hara furnaces; and these giving satisfaction, the original O'Hara's were remodeled to the Allen-Brown-O'Hara type,

and the Brückner cylinders thrown out. In 1892, when the plant burned down, eight Allen-Brown-O'Hara furnaces were in operation. The plant was immediately rebuilt, the Allen-Brown-O'Hara furnaces were repaired, but not the Brückner cylinder. A new blast furnace, 96 by 36 inches and 16 feet high, was erected to take the place of the old small cupola. This furnace was originally provided with a bell-and-hopper feed, which proved too expensive. In 1901 the width of the new furnace was increased to 40 inches, and the height reduced to 11 feet. Up to 1893 the blast furnaces smelted little but roasted concentrates. Matting reverberatory furnaces remodeled and enlarged in 1895. Converter plant started in 1900. Present plant: eight Allen-Brown-O'Hara roasting furnaces (hearths 90 by 9 feet), four matting reverberatories (hearths 50 by 20 feet, the first furnaces of this size having been built in 1899–90), one blast furnace 96 by 44 inches at tuyères and 9 feet high, and three horizontal converters with barrels 10 feet 6 inches by 7 feet.

The Montana Ore-Purchasing Company. — Ground broken for smelting works October 17, 1892; first matte tapped January 1, 1893. Ore roasted in two Allen-Brown-O'Hara furnaces (hearths 9 by 100 feet, each treating 60 tons in twenty-four hours), and smelted in two reverberatory matting furnaces (hearth 12 feet 10 inches by 20 feet, and fire box 5 by 6 feet; natural draught, stack 80 feet high and 4 by 4 feet in the clear, and charge 7 to 8 tons; time of melting three and five-tenths to four hours), and one blast furnace 42 inches diameter at tuyères. After a year's run, blast furnace replaced by two matting reverberatories like those first built. In 1894 two Herreshoff furnaces (9 feet inside diameter, 5 hearths) were added to roasting department. These giving satisfaction, eight more were erected at once, thirty in 1895, and thirty in 1899, making in all seventy Herreshoffs. The O'Hara's destroyed by fire 1901, and not rebuilt. Early in 1894 hearths of matting reverberatories were enlarged to 13 feet 6 inches by 25 feet, fire boxes, however, remaining 5 feet by 6 feet; at same time fuel was changed from lump to slack coal, and undergrate blast substituted for natural draught. These changes increased the tonnage per furnace for twenty-four hours by 10 to 15 tons. Furnaces again enlarged 1898, and two more built 1899, making six in all (hearth 16 by 33 feet, fire box 6 by 8 feet, stack 80 feet high and 5 by 5 feet in the clear).

January, 1900, two blast furnaces (42 by 120 inches at tuyères;

11 feet from tuyères to throat; cast-iron water jackets) were blown in. These water jackets giving much trouble by cracking, furnaces were replaced by larger furnaces (42 by 160 inches at tuyères and 10 feet 6 inches in height) with steel water jackets. Converting plant started August, 1893, with two vessels of the Parrot type (5 feet external diameter); in 1894 two were added, and in 1899–1900, four more. Two barrel converters (bowls 10 feet 6 inches long and 7 feet in diameter), installed 1901, are in constant use, and the upright Parrot converters are worked only when these are unable to handle all the matte. It is the intention to erect two additional horizontal and to remove the remaining upright converters. Present plant: seventy Herreshoff roasters, six reverberatory matting furnaces, four blast furnaces, two horizontal and eight upright converters.

The Anaconda Copper Mining Company. — At Anaconda there are three separate plants, the Upper, the Lower, and the New or Washoe Works. The Upper Works of the Anaconda Copper Mining Company were started by Marcus Daly in 1883 with thirty-four hand reverberatory roasting furnaces (hearths 50 by 14 feet), twenty-six reverberatory matting furnaces (hearths 20 by 14 feet), and two 70-ton water-jacket blast furnaces. A reverberatory smelting charge weighed 3 tons, and 15 tons were treated in a furnace in twenty-four hours. In 1885 two Brückner roasting furnaces were added. After fire of 1889 works rebuilt, and remained practically unchanged until closed down in November, 1901. At that time they contained forty Brückner roasting furnaces with cylinders 18 by 9 feet, four MacDougall roasting furnaces (16 feet diameter and 21 feet high, with six hearths), four Wethey calciners, with hearths 100 by 12 feet, and eleven reverberatory matting furnaces, with hearths 31 by 16 feet, a matting furnace taking 9-ton charges and treating 60 tons of ore in twenty-four hours.

The Lower Works of the Anaconda Copper Mining Company, located about two miles below the Upper Works, were built under Marcus Daly by O. Stallmann. The smelting department was started December, 1888, with fifty-six Brückner cylinders (9 feet 6 inches by 18 feet) and twenty-eight reverberatory matting furnaces, with hearths 22 by 16 feet, a matting furnace receiving 6-ton charges and treating 40 tons ore in twenty-four hours. The smelter buildings, which were entirely of timber, were totally destroyed in March, 1889, by a fire which started in the coal bins. They were quickly replaced by a steel structure. In 1890 forty Brückner furnaces of the same size as the first

ones were added to the plant, and in 1899 were added four MacDougall furnaces of the Evans-Klepetko pattern (16 feet diameter and 21 feet high, with six hearths). Of the twenty-eight original matting furnaces, seven were enlarged in 1899; three had hearths 32 by 18 feet, 33 by 18 feet, and 45 by 18 feet; and four, hearths 35 by 18 feet. They were charged with about 11 tons of ore, and averaged 75 tons in twenty-four hours.

The converter plant was started in 1890 with fifteen stalls for upright vessels, 10 feet high and 6 feet in diameter. In the same building were six blast furnaces 8 feet by 3 feet 6 inches at tuyères and 10 feet high.

New Electrolytic Refining Plant,[1] still in full operation, started in 1894, refines part of the converter copper of the Washoe works, the rest being shipped to Baltimore for treatment. The old experimental plant,[2] started in 1891 and closed in 1893, contained 630 tanks.

The New or Washoe Works[3] of the Amalgamated Copper Company were planned and erected by F. Klepetko. They are located on the site selected by the Washoe Copper Company (incorporated about 1893) for a new plant. When the Amalgamated Copper Company obtained control of the Anaconda and Washoe Companies, it was decided to erect new works instead of remodeling and enlarging those of the Anaconda Copper Company. The works were started in 1902, contain forty-eight six-hearth MacDougall-Evans-Klepetko roasting furnaces 16 feet diameter and 21 feet high; five blast furnaces (56 by 180 inches at the tuyères and 14 feet 10 inches high); fourteen matting reverberatories (hearth 20 feet by 50 feet 2 inches), and eight converter stands (barrels 12 feet 5 inches long and 8 feet in diameter). The fumes from these four departments are drawn off by four steel stacks, 200 feet high and lined throughout (inner diameter 20 feet; outer, 23 feet 6 inches). Since fumes damaged crops in the Deer Lodge Valley, it has been decided to deliver them 500 feet higher up into the air. The fumes from the four departments will be conducted through branch flues into one brick main 2,300 feet long, built on a hillside, and ending in a stack 300 feet high and 30 feet inner diam-

[1] *Berg- und Hüttenmännische Zeitung*, 1893, p. 53. *Zeitschrift für Electrochemie*, 1901, p. 793. *Engineering and Mining Journal*, Sept. 19, 1896.

[2] *Mineral Resources of the United States*, 1891, p. 92.

[3] *Engineering and Mining Journal*, March 1, 1902. *Western Mining World*, March 8, 1902.

eter. The main will be 37 feet deep; the first 1,300 feet will be 60 feet wide, and the remaining 1,000 feet 120 feet wide. Underneath will be a tunnel to receive the cars, into which will be discharged the flue dust. It is expected that the new addition will be finished this summer.

Boston and Montana Consolidated Copper and Silver Mining Company's Great Falls Plant. — Ground broken in the spring of 1890. Plant first consisted of twenty-four Brückner roasters (cylinders 8 by 16 feet), eight tilting reverberatory matting furnaces (hearth 13 by 16 feet), and two 5-ton upright converters. Matting furnaces having regenerative chambers and fired with producer gas resembled the Campbell open-hearth steel furnaces. Plant has been greatly enlarged since 1890, under the management of F. Klepetko, and furnaces much changed to meet constant demand for increased capacity. Present plant: twenty-four Brückner cylinders (8 by 16 feet), all idle except two or three used for drying slimes from the concentrator; eighteen six-hearth MacDougall-Evans-Klepetko roasting furnaces (16 feet diameter and 21 feet high); five gas-heated stationary matting reverberatories with regenerative chambers, four of which have hearths 42 feet 6 inches by 15 feet 9 inches, and one a hearth 29 by 12 feet; five blast furnaces (18 feet high to charging floor; four are 56 by 180 inches, and one 44 by 180 inches at tuyères); twelve 5-ton upright converters (7 feet diameter and 14 feet 7 inches high); one anode-casting reverberatory (hearth 14 feet 8 inches by 22 feet 6 inches) with Walker casting machine; and an electrolytic copper refinery with 312 tanks and four copper-refining furnaces of different sizes.

The early history of this company may be summarized by the beginnings of the several operations: concentrator, March, 1891; Brückner cylinders, April, 1892; reverberatory matting furnaces, April, 1892; converters, August, 1892; blast furnaces, April, 1893; refining furnaces, January, 1893; electrolytic refinery, February, 1893.

In concluding this introductory account, it should be stated that nearly all smelting works have concentrating works in which second-class ore is enriched.

III. The Ores.

The ores of the Butte district are classified by Goodale[1] as copper-silver ores, silver-copper ores, and silver ores. The copper-bearing minerals of the copper-silver ores are chalcocite, bornite, enargite, and chalcopyrite; the gangue is quartz and feldspar. The copper- and silver-bearing minerals of the second class are wurtzite, sphalerite, bornite, chalcopyrite, pyrite, tetrahedrite, enargite, tennantite, and galenite; the gangue is quartz and feldspar, with some barite and fluorite. Of the silver ores, which are of secondary importance, the silver-bearing minerals are pyrite, sphalerite, galenite, tetrahedrite, and argentite; the gangue is quartz, rhodocrosite, and rhodonite. With regard to metallurgical treatment, the copper-bearing ores are divided into first and second class. The line of division varies with the different mines. In general, first-class ore contains 10 to 15 per cent. copper, and is smelted direct, usually in the blast furnaces, without having been roasted. Second-class ore, which forms about 90 per cent. of the ore mined and contains from 3 to 6 per cent. copper, is concentrated; fine concentrates are always roasted and, as a rule, smelted in the reverberatory matting furnaces; coarse concentrates, above 5 millimeters in size, are often added to the blast-furnace charges without having been roasted, the proportion amounting to from 30 to 35 per cent. of the charge.

The following partial analyses of 1902, taken from smelting records, give the general character of the ore now treated. The analyses of 1896, given by Goodale[2] and here quoted for comparison, show much higher values.

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[1] *Transactions American Institute of Mining Engineers*, XXVI, p. 599.

[2] *Op. cit.*, p. 639.

TABLE I. — Analyses of Butte Ores.

Plant.		A.												B.	C.			D.	
		First-class ores.	First-class ores.	First-class ores.	First-class ores.	Second-class ores.	Coarse concentrates.	Coarse concentrates.	Fine concentrates.	Fine concentrates.	Fine concentrates.	Slimes.	Slimes.	Average.	First-class ores.	Second-class ores.	Concentrates.	First-class ores.	Concentrates
Cu . . .	21.35	15.15	13.80	8.60	8.05	5.9	15.85	15.60	13.45	10.80	9.50	7.20	4.80	7.00	12.7	5.2	8.7	9-10	10
Fe . . .	10.75	19.50	. .	18.25	12.10	. .	21.95	22.00	25.90	22.60	22.00	8.40	5.10	24.00	18.4	16.0	27.0	16-20	30
Zn . . .	0.50	trace	. .	0.55	. .	. .	0.50	. .	trace	. .	trace	. .	trace	12.00	. .	. .	. .	. .	. .
S	20.30	28.93	. .	23.50	15.37	. .	29.10	29.70	34.70	29.50	28.46	11.70	7.40	32.00	24.8	19.8	34.7	20-25	34-39
Mn . . .	. .	trace	. .	. .	trace	. .	trace	. .	trace	. .	trace	. .	trace	. .	. .	. .	. .	. .	. .
As . . .	1.70	2.10	. .	0.70	1.26	. .	0.95	. .	0.40	. .	0.90	. .	0.10	. .	. .	. .	. .	. .	. .
Sb . . .																			
Pb . . .	trace	trace	. .	trace	trace	. .	trace	. .	trace	. .	trace	. .	trace	. .	. .	. .	. .	. .	. .
Al_2O_3 . .	3.15	7.00	. .	6.15	10.60	. .	3.00	. .	5.70	. .	7.60	. .	20.70	. .	4+	. .	. .	. .	. .
CaO . . .	0.50	0.28	. .	0.30	0.54	. .	0.45	. .	0.60	. .	0.00	. .	trace	. .	. .	. .	. .	. .	. .
MgO . .	trace	trace	. .	trace	trace	. .	trace	. .	trace	. .	trace	. .	trace	. .	. .	. .	. .	. .	. .
Insol. . .	42.25	30.35	. .	47.20	56.50	. .	30.30	30.40	21.60	34.00	35.90	66.66	76.50	23.00	40.0	56.0	25.4	45-50	22-24
SiO_2 . . .	36.80	25.50	. .	39.30	49.70	. .	26.50	. .	18.15	. .	29.50	. .	53.45	. .	. .	. .	. .	. .	. .
H_2O . . .	. .	. .	. .	. .	. .	. .	. .	1.60	4.7	5.80	. .	29.80	. .	. .	. .	. .	. .	. .	. .
Ag, oz. p. t.	5.50	8.70	. .	3.00	3.90	. .	5.00	6.10	. .	4.70	4.00	3.40	2.80	14.00	7.6	3.0	5.6	. .	. .
Au, oz. p. t.	0.018	0.014	. .	0.016	0.010	. .	0.02	. .	. .	. .	. .	. .	. .	. .	0.032	none	0.0025	. .	. .

Note. — Analyses under A to F, inclusive, represent 1902; G, H, I, and J are Mr. Goodale's figures for 1896.

TABLE I.—ANALYSES OF BUTTE ORES.—*Continued.*

PLANT.	E.			F.	G.		H.		I.		J.
	First-class ores.	Coarse concentrates.	Fine concentrates.	Silver ores.	Silver ores.	Smelting.	Concentrating.	Smelting.	Smelting I.	Smelting II.	Concentrating.	Smelting.	Concentrating.
Cu	8.0	6.0	9.0	0.30	0.40	20.26	6.50	9.80	29.96	26.25	8.10	0.55	0.10
Fe	13.2	18.6	1.42	5.90	7.90	14.42	9.55	26.00	18.65	16.40	10.10	5.10	4.90
Zn	. .	. .	. .	11.90	22.50	5.30	8.66	. .	7.25	2.34	. .	16.29	4.60
S	18.0	23.0	34.0	9.70	21.00	26.34	15.87	33.60	36.15	29.18	14.88	13.19	6.43
Mn	. .	. .	. .	7.43	1.70	0.45	0.09	. .	0.26	. .	. .	6.73	5.56
As	. .	. .	. .	0.20	0.10	1.66	0.94	. .	0.44	4.00	. .	trace	. .
Sb	. .	. .	. .			trace	0.20	. .	. .	. .	. .	0.05	. .
Pb	. .	. .	. .	3.50	8.20	trace	0.25	. .	. .	. .	. .	8.55	2.44
Al_2O_3	. .	. .	. .	7.70	2.90	2.35	. .	. .	. .	. .	. .	. .	. .
CaO	. .	. .	. .	4.00	2.10	. .	. .	. .	. .	. .	. .	. .	. .
MgO	. .	. .	. .	1.80	0.80	. .	. .	. .	. .	. .	. .	. .	. .
Insol.	54.0	45.0	28.0	51.00	30.40	28.72	54.80	28.70	7.26	21.50	63.00	43.22	66.50
SiO_2	. .	. .	. .	41.70	26.20	. .	. .	. .	. .	. .	. .	. .	. .
H_2O	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Ag, oz. p. t.	6.5	. .	. .	67.50	24.20	30.00	10.00	11.2	24.00	20.00	6.5	43.00	20.00
Au, oz. p. t.	n. d.	. .	. .	0.13	0.60	$0.44	$0.44	n. d.	n. d.	n. d.	n. d.	$0.80	$0.40

NOTE.—Analyses under A to F, inclusive, represent 1902; G, H, I, and J are Mr. Goodale's figures for 1896.

IV. METALLURGICAL TREATMENT — THE ROASTING OF ORES.

The metallurgical processes in the Butte district show much uniformity with regard to the general principles on which they are based. They comprise roasting, smelting, converting, electrolytic refining, and casting. There is considerable diversity in the details of practice.

First-class ore, forming about 10 per cent. of the product of the mines, is, as a rule, smelted raw, and furnishes the desirable coarse ore of the blast-furnace charge. Concentrates, coarse limestone, and converter slag are the basic fluxes added to slag the siliceous gangue. In one instance some first-class ore is roasted in lump-form in stalls. This makes it less refractory than raw ore, and, furnishing available iron, permits the running of slags richer in iron, and hence more fusible than would be otherwise possible.

Heap roasting, which was practiced in the early days, has been entirely abandoned.

In crushing, the copper-silver ores readily break into small grains, making often more fines than can be carried by a stall or even by a blast furnace. This necessitates separating part of the fines by screening, the screenings going into the fine-ore roasting furnaces.

The form and general arrangement of the *open stalls* now in operation are the same as given by Peters.[1] The management, however, differs slightly from the description given by him. In making the bed of decayed wood, first used by A. J. Schumacher at the Parrot works, no attention is paid to an open cross channel to start the fire.[2] While Peters prefers to close the front of the stall with large pieces of lump ore, at Butte it is closed down to 2 feet from the bottom with a plate of sheet iron, which is braced by iron cross bars to prevent bulging caused by the swelling of the ores while roasting. The plate is supported by blocks of wood, between which are placed small sticks and kindling. During the roast, when the contents of the stall have risen to the highest point and begin again to shrink on account of the slight clinkering which always takes place, the front plate gradually glides down to the floor. A stall holding 30 tons of first-class ore, with about 10 per cent. of copper and from 30 to 35 per cent. of sulphur, burns thirty days, the sulphur being reduced to 3.5 or 4 per cent.

Crushing and sampling the ore, running it to the stalls, and filling and emptying the stalls is done by contract.

The fine-ore furnaces are represented by four types, the Allen-O'Hara, the Wethey, the Pearce, and the MacDougall; long-hearth reverberatory furnaces used in early times having been given up entirely.

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[1] *Modern Copper Smelting*, 1895, p. 148.

[2] See Peters, *op. cit.*, Fig. 21, p. 151.

The Allen-O'Hara Furnace.[1] — This is one of the permanent improvements on the original O'Hara furnace.[2] The two superimposed hearths are each 9 by 90 feet; the six carriages with their plows make the circuit in three and three-fourths minutes. Thus the ore lying about 3 inches deep is stirred every thirty-seven seconds, and remains about six hours in the furnace. A test showed that 3.64 horse power was required to run the furnace. The ore charged is a mixture of concentrates and fines from first-class ore, usually in the proportion of $4\frac{1}{2}$: 1, containing about 35 per cent. of sulphur.

From 47 to 50 tons of charge is roasted in twenty-four hours, or 60 pounds per square foot of hearth area, the sulphur being reduced to 8 per cent. One hundred pounds moist ore gives 72.7 pounds of calcines and one pound of flue dust. A furnace is attended in an eight-hour shift by one-half carman, who brings the ore; one-half fireman; one wheeler, who removes the calcines to the smelting department, and one-eighth repair man during the day shift only. A partial analysis of an average sample of roasted ore gave: Cu, 10.8; SiO_2, 31.6; Fe, 38.0; S, 7.6; Ag, 7.3 ounces per ton. One of flue dust: Cu, 10.8; SiO_2, 34.4; Fe, 36.5; S, 8.2; Ag, 7.2 ounces per ton.

The Wethey Furnace.[3] — The furnaces in operation each have four superimposed hearths. The furnaces erected in 1894 had two sets of hearths, each 50 by 5 feet, with the rabble carriages running between them, the arms projecting from the inner sides into the hearth. The furnaces erected since 1894 have been increased to 65 by 10 feet, with the rabble arms protruding on both sides and carried on carriages on the outside of the furnace hearths. The tripping doors, which close the continuous hearth slot, are not being repaired as they wear out, the furnace seeming to do satisfactory work without them. The position of the fire box, which was built at first to heat the second floor, has been changed so that the flame may enter the top hearth and dry and kindle the moist concentrates and slimes as they enter the furnace. While the smaller size furnace, with a hearth area of 2,000 square feet, puts through at the present time 60 tons of raw material with 35 per cent. sulphur, or 60 pounds per square foot of hearth area, reducing the sulphur to 8 per cent. and consuming 5.5 per cent. of slack coal, the

[1] Peters, *Modern Copper Smelting*, 1895, pp. 200–205. Hofman, *Metallurgy of Lead*, 1899, pp. 186–190.

[2] Küstel, *Roasting Gold and Silver Ores*, San Francisco, 1880, p. 84. Fraser and Chalmers, *Catalogue*, No. 4, 1891, p. 135.

[3] Hofman, *Metallurgy of Lead*, 1899, pp. 195–198.

larger size furnace, with an area of 2,600 square feet, roasts in twenty-four hours 90 tons of ore, with 35 per cent. of sulphur, or 70 pounds per square foot of hearth area, reducing the sulphur to from 5 to 6 per cent. and consuming somewhat under 4 per cent. of slack coal. One fireman attends each furnace.

The improvement in the work of the longer furnaces is due to the heat from the fire box having to travel a longer distance before it escapes to the flue, and to the ore traveling in a direction opposite to that of the flame, whereby the heat is more fully utilized than with the shorter furnace.

The Pearce Turret Furnaces.[1] — Three kinds of turret furnaces are roasting ores, the single- and double-deck furnaces of R. Pearce, and the six-deck furnace of R. F. Pearce. A single-deck furnace 36 feet in diameter, with a 6-foot hearth (or a hearth area of 505 square feet) and two stirrer arms, roasts in twenty-four hours 14 tons of concentrates (Cu, 7 per cent.; Fe, 24 per cent.; Zn, 12 per cent.; S, 32 per cent.; SiO_2, 23 per cent.; Ag, 14 ounces per ton), reducing the sulphur to from 7 to 8 per cent. and burning 400 pounds of coal per ton of ore.

The percentage of flue dust is very low.

The 36-foot furnace does better work than the first one built, which has the same width of hearth (viz., 6 feet), but is only 30 feet in diameter. If, nevertheless, the tonnage appears to be comparatively low and the percentage of sulphur left in the roasted ore somewhat high, this must be attributed to the large amount of zinc present.

In the double-deck furnaces, in which the ore fed on the upper hearth drops through a slot in the roof onto the lower hearth, the floor of the upper hearth and the roof of the lower hearth are separated, it will be remembered, by an air space 2 feet high. A furnace with a 6-foot hearth (area 1,010 square feet) treats in twenty-four hours 30 tons of concentrates (59 pounds per square foot of hearth area), containing Cu, 12 per cent.; Zn, 8 per cent.; S, 35 per cent.; Fe, 25 per cent.; As, 3 per cent.; SiO_2, 16 per cent.; Ag, 20 ounces per ton, with a reduction of the sulphur to from 6 to 7 per cent., 400 pounds of coal being burned per ton of ore.

A furnace with a 7-foot hearth (area 121,829 square feet) treats 42 tons (69 pounds per square foot hearth area) with a similar elimina-

[1] Peters, *Modern Copper Smelting*, 1895, pp. 205–214; Hofman, *Metallurgy of Lead*, 1899, pp. 175–182.

tion of the sulphur and a fuel consumption of 182 pounds per ton of ore treated.

Comparing the pounds of ore roasted per square foot of hearth area in the two furnaces (59 and 69 pounds), an improvement of 15 per cent. in favor of the 7-foot hearth is seen — the degree of desulphurization is about the same in the two furnaces; the consumption of fuel, however, has been reduced from 400 to 182 pounds, or 55 per cent. The labor required to fire a single-deck furnace is the same as with the double-deck, and that for supplying ore and fuel and removing roasted ore and ashes from one double-deck furnace is, of course, smaller than from two furnaces with single hearths. Thus the double-deck furnace is a decided improvement over the single hearth as long, be it understood, as ores are treated which do not frit or form accretions on the hearth.

The six-deck furnace[1] resembles the double-deck furnace in the stirring mechanism, and with it in the passage of ore and gases; it has one fireplace (3 feet by 3 feet 2 inches) on the top hearth, and one 4 feet 3 inches by 3 feet 2 inches on the bottom hearth.

It differs from the double-deck furnace in the number of hearths, 6 *versus* 2; in the fact that there are no air spaces between the superimposed hearths, the roof of one forming the floor of the next one above; and that the portions of the inner wall above the horizontal slots of hearths one to five have cantilever supports with trussed cords projecting from the central column. This makes rather a complicated structure, requiring a large number of iron parts of various sizes, some of considerable weight. The iron parts of the furnace weigh 165 tons. The furnace is 32 feet in diameter and 20 feet 9 inches high; the hearths, 7 feet wide, are 2 feet $9\frac{1}{2}$ inches from roof to roof, which is $4\frac{1}{2}$ inches thick; the sand filling forming the working hearth is 5 inches thick at the crown of the roof and 12 inches at the sides; the distance from the working hearth to the inner slot (protected by 1-inch castings) is 6 inches, and to the springings of the arch 16 inches; the rise of the arch is 8 inches. A hearth has four stirring arms making one revolution in sixty-five seconds. The horizontal flues in the outer walls are omitted, through which air passes in the older furnaces in order to be warmed and admitted to the surface of the roasting ore. Around the furnaces are platforms to facilitate access to the hearths. The moist concentrates, dumped into the shoe of a bucket elevator, are

[1] *United States Patent*, No. 671,071, April 2, 1901.

raised to the top of the furnaces and discharged into a hopper, partly closed at the bottom by a corrugated roller feed; this delivers into a slot 8 inches wide by 7 feet long in the roof of the top hearth. The furnace roasts 56 tons ore in twenty hours, or 38 pounds per square foot of hearth area; it makes 4 per cent. of flue dust on the weight of the ore charged, and requires 28.5 pounds slack coal per ton of ore. The quality of the work is similar to that of the double-deck furnace; the amount of ore roasted per square foot of hearth area is a great deal smaller, but the saving of fuel is much larger. The low fuel consumption brings out in a striking way the benefits that are derived by diminishing the loss of heat by radiation.

The MacDougall Furnaces. — This is a vertical cylindrical furnace with arched horizontal hearths having discharge openings alternately near the centre and periphery, and a central revolving shaft with horizontal radial stirring arms, which are provided with teeth placed at an angle to the arm. The teeth of the arms on the even-numbered hearths are set in a direction opposite to that of the odd-numbered, thus on the odd-numbered hearths they push the ore toward the centre, and on the even-numbered toward the side. The ore, fed mechanically onto the furnace, is delivered continuously onto the outer edge of the first hearth, where the teeth of the stirring arm turn it over and work it toward the centre, where it drops through an annular opening onto the second hearth; the arms of this turning the ore over and over will convey it slowly to the openings near the periphery, through which it drops onto the third hearth and so on until it arrives on the closed bottom, where it falls through drop holes into a hopper.

The ore spread evenly over the hearth thus travels in zigzag through the furnace, passing from periphery to centre and *vice versâ*. It is warmed at the top of the furnace; it then ignites and burns freely; and lastly most of the sulphates formed are decomposed lower down. The air necessary for oxidation is admitted through doors in the side, most of it entering on the bottom hearth. The gases, and with them the dust, pass upward through the ore-discharge openings, and are drawn off through pipes in the roof. In starting, the furnace has to be heated up to the kindling temperature of the ore, which, if rich enough in sulphur, will burn of its own accord without the use of any carbonaceous fuel. If too low in sulphur, the heat necessary for successful roasting has to be supplied by one or more external fireplaces.

Three kinds of MacDougall furnaces interest us here: the Original MacDougall, the Herreshoff, and the Evans-Klepetko.

The Original MacDougall Furnace.[1] — This furnace, patented by MacDougall Brothers in the beginning of the seventies, was in operation in Liverpool, England, burning pyrites to furnish sulphurous gases for the manufacture of sulphuric acid. It had to be abandoned on account of the large amount of flue dust formed and the many mechanical difficulties encountered. The furnace, 6 feet in diameter and 12 feet high, was built of seven cast-iron cylinders bolted together, and had six closed chambers. The vertical solid shaft, 6 inches in diameter, had cast-iron stirring arms. A 2-horse power engine was sufficient to drive the mechanism. The furnace roasted in twenty-four hours $3\frac{1}{2}$ tons pyrites, or 0.020 tons per square foot of hearth area, reducing the sulphur to 2 per cent.

The Herreshoff Furnace. — Most of the Herreshoff furnaces in operation at Butte have a $\frac{1}{4}$-inch steel casing; they are 10 feet 10 inches in diameter and 11 feet 6 inches in height, and are lined with a full course of red brick. A few furnaces built of two full courses of brick and hooped with iron bands only are doing better work in cold weather than the furnaces that are sheeted and lined with a single course, thus showing that with ores running low in sulphur, when heat has to be husbanded, an 18-inch side wall has its advantages. A furnace has five arched brick hearths $4\frac{1}{2}$ thick and 12 and 13 inches apart; the pitch of the arch is $4\frac{1}{2}$ inches; a current of air passes through the hollow central revolving shaft, which is 14 inches in diameter. The hollow horizontal cast-iron stirring arms, two to a hearth, have seven and eight teeth, respectively; they are easily exchanged when worn out.

The top hearth acts as a dryer; the second starts the roasting; on the third the ore roasts freely (innumerable sparks are seen); on the fourth there are no sparks; and on the fifth the ore looks dark. A furnace, with its shaft making fifty revolutions per hour, roasts in twenty-four hours from 5 to 6 tons of wet concentrates with about 35 per cent. of sulphur, or 0.015 tons per square feet of hearth area, reducing the sulphur to 6 per cent. Seventy furnaces make from 4 to 5 tons, or 6.4 per cent. of flue dust.

In Eastern sulphuric acid plants this furnace[2] treats in twenty-four

[1] Lunge, *Sulphuric Acid and Alkali*, London, 1891, I, pp. 260–264. Also, *The Mineral Industry*, 1898, VI, p. 235.

[2] *The Mineral Industry*, VI, pp. 235–238.

hours from 3 to 4 tons of pyrites, with 44 per cent. of sulphur, or 0.0098 tons per square foot of hearth area, reducing the sulphur to from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent.; the shaft makes thirty revolutions per hour.

The Evans-Klepetko Furnace.[1] — Shortly after the Herreshoff furnace had proved a success, a larger furnace,[2] 16 feet in diameter, was constructed on the same general lines; it had eight hearths, an air-cooled shaft, and eight solid cast-iron arms. The heat generated was sufficient to cause the arms to bend under their own weight. Air-cooling having proved unsatisfactory, water-cooling was substituted, and the number of hearths reduced from eight to six. The leading differences then between the Evans-Klepetko and the Herreshoff furnaces are the size and the water cooling of the central shaft and the stirring arms. The furnace is 18 feet $3\frac{1}{2}$ inches high and 15 feet 10 inches in diameter; it is sheathed with $\frac{3}{8}$-inch boiler iron, and lined with a full course of red brick; it has six arched hearths with a 9-inch spring and 3 feet apart; each hearth has two stirring arms making sixty circuits per hour. The furnace stands on columns 12 feet high to allow the roasted ore to be collected in hoppers and discharged into cars. Six (resp. eight) furnaces form a battery; they are placed from centre to centre 18 feet apart in one direction and 21 feet 3 inches in the other. Each furnace has two gas flues, 2 feet in diameter and 12 feet apart, passing out of the roof; the flues from three furnaces lead into one main 6 feet (resp. 7 feet) in diameter, having openings along the top and bottom for removing the flue dust; the bottom openings have vertical pipes which are connected directly with the calcine hoppers. The central shaft of a furnace is driven from below. Three (resp. four) furnaces receive their motive power from one main shaft, with which they are connected by friction clutches. A clutch can be thrown in or out from each of the three platforms surrounding a furnace. The cooling water is forced down to near the bottom of the revolving hollow shaft (9 inches inner diameter) through a 3-inch pipe and out to the ends of the horizontal stirring arms through 1-inch horizontal pipes. In its upward passage between shaft and pipe it takes up the return water from the stirring arms, and discharges at the top through two spouts into a stationary launder. Shaft and arms are made

[1] *United States Patent*, No. 700,399, May 13, 1902; Drawing, see *Canadian Mining Review*, April 30, 1903.

[2] C. H. Repath, "The Mechanical Engineer, a Factor in Modern Mining, Milling, and Smelting," Mining Congress, Butte, Sept. 3, 1902, through *Mining and Scientific Press*, Sept. 13, 1902.

up of flanged sections to permit easy exchange. Running the overflow-water at 80° C., 20 gallons of cooling water per minute are required by a furnace. Forty-eight furnaces are supplied with the necessary draft by a steel stack 200 feet high, lined throughout (inner diameter 20 feet; outer, 23 feet 6 inches). A 30-horse power motor is provided to run the machinery. Tests have since shown that 10 horse power is required for six furnaces. When ore too low in sulphur to be self-burning, *i. e.*, about 28 per cent., is to be roasted, one auxiliary fireplace for two furnaces, placed on the level of the bottom floor and delivering the flame onto the fourth floor, furnishes the additional heat required.

The moist concentrates, arriving from the ore-dressing plant on an overhead track, are dumped into the two feed hoppers of a furnace. These are 10 feet apart, and are 4 feet 6 inches in diameter for 9 feet 6 inches, and then conical for 7 feet 6 inches. At the bottom they are made 3 feet 6 inches by 1 foot 2 inches to fit into the openings in the roofs of the furnaces. The top of the hopper has a grating to break up any lumps and to keep out large pieces that may have accidentally gotten into the ore. The hopper holds two cars of concentrates, or 33 tons. This weight, pressing downward, prevents any hanging of the charge, and thus solves the difficulty of feeding moist fine concentrates. The contents of the hopper are continuously discharged into the furnace by means of a feeding device of the form of an I, which passes to and fro under the mouth with a throw of about 10 inches. The rods of the two feeders are joined by a cross-piece, which is pivoted in the centre and connected by a rod to one end of a link, while the other end is attached to the pitman of a crank and spur wheel; the spur wheel is geared to the central shaft of the furnace. The ore is spread on the top hearth to the thickness of 3 inches by the stirring arms. The tops of these arms are protected by cast-iron caps against rapid wear at the places where they strike the ore column coming down through the feed openings. The outer half of a hearth is 9 inches thick, the inner 6 inches. The reasons for the difference are: saving of brick, reducing of weight at centre, preventing contact with stirring teeth when the hearth rises upon heating, and furnishing an offset to hold the loose working bottom (crushed limestone, sometimes flue dust and even coke dust) which is about 4 inches thick at the centre and 9 inches at the periphery. The two arms of a hearth have seven and eight cast-iron teeth; these are 8 inches long by 6 inches wide by $\frac{5}{8}$ inch thick; the lower 3 inches of the teeth, which come in contact

with the ore, are chilled. There is no advantage in making the teeth thicker than $\frac{5}{8}$ inch, as they wear off obliquely to the working surface, and consequently would simply offer a larger wearing surface but not lengthen the life. At the same rate that the teeth are worn off the ore builds on the loose working hearth. When they are to be renewed they are removed, and a plow is slipped over the stirrer arm and moved a little toward the centre after every circuit of the arm. Thus a crust is easily and surely broken up. The crusts on the second hearth are harder to break than those of the other hearths. The teeth on the top hearth last from twenty-five to thirty-four days; those on the sixth, from six to eight months. The shorter life of the former is attributed to mechanical wear caused by decrepitation of the ore. It cannot be due to chemical action, as the top hearth serves mainly for drying, unless the moisture should cause some sulphuric acid to form; but the temperature of the escaping gases is 315° C., and the draught is sufficiently strong to show a depression of 0.3 inches of water.

Roasting begins on the second or third hearth, varying with the strength of the draught and the number of circuits that the stirring arms make. With a strong draught the heat creeps up; with one circuit in fifty-five seconds the roast begins on the second hearth; with one in seventy-five seconds on the third. As the ore passes from the first hearth through the annular opening at the centre of the roof of the second hearth (protected by a cast-iron ring), it strikes a distributor which prevents any of it from passing down the shaft. During normal work three doors on the bottom hearth are left open for the admission of air. If the furnace becomes too hot, the doors on the third floor are opened more or less, and thus the draught checked. While the ore drops from hearth to hearth, the upward gas current carries with it dust, and this striking the roof adheres to it in part and builds. In order to protect the arms from being worn out at these places, they are protected by cast-iron caps. When the dust has grown to a thickness of 4 inches it is removed with chisel-pointed bars. Experiments with cast-iron plates to protect the roof at weak spots have proved successful, as the dust is easily pried off. The chunks of fritted dust go to the blast furnace as welcome lump ore; they contain only 6 per cent. of silica with ore of 30 per cent. silica, thus showing that light particles of ferric oxide are more easily carried away by the gas currents than heavy gangue. The dust collected in the settling chambers runs higher in sulphur than the roasted ore.

In starting a furnace crushed limestone is fed to form the working

bottom. Then a small fire of dry, soft, *i. e.*, long-flame, wood is started from the three side doors on the third and fifth hearths. A new furnace is brought to a dark red in from three to four days; an old furnace requires only two days. Now concentrates are fed. After charging for from five to six hours, it sometimes happens that the furnace cools down too much, and this makes it necessary to start on the third and fifth floors a new fire for from one and one-half to two hours; occasionally feeding of the ore is stopped and half a ton of coal is charged. When this has come to the third hearth the machinery is stopped and the coal is allowed to burn out. The kindling of the coal may have to be assisted by placing dry wood on the hearth. Under normal conditions a furnace does its best work when the flue shows a depression in water of 0.3 inch; if it is less, the furnace gets cool. The normal ore mixture passes through the furnace in about one and one-half hours. If the furnace gets too hot, more slimes are fed; if too cold, coarser concentrates are charged, and the rate of feeding is reduced. As indicated above, the temperature is further regulated by the admission of air; closing the bottom doors drives up the heat, opening them draws it down; opening doors higher up checks the draught. The rate of feed when once settled upon is usually not altered, and the number of circuits the arms make per hour remains, of course, constant.

The dust, which collects in the flue connecting three (resp. four) furnaces and forms from 4 to 5 per cent. on the ore, is raked out every day; sometimes part of it is blown into the main flue of a battery with a hose under a pressure of about 90 pounds per square inch. The loss of weight in ore, including flue dust, is about 20 per cent.

A furnace treats under normal conditions in twenty-four hours 40 tons sulphide ore, with 35 per cent. sulphur and 10 per cent. copper, or 0.042 ton per square foot of hearth area, reducing the sulphur to 7 per cent.; roasted ore, with 14 per cent. copper treated in the same manner, retains about 10 per cent. of sulphur. The product can, of course, be varied with the speed of travel of the stirring arms. Thus with one circuit in seventy-five seconds it is reduced to 30 tons; with one in fifty seconds it is increased to 50 to 55 tons.

A section of 6 (resp. 8) furnaces is tended to in an eight-hour shift by one-third foreman, one furnace man, one helper, one-sixth oiler, one-ninth repair man, and one trimmer.

The following partial average analysis of roasted ore represents two determinations from the average day-and-night samples, taken during an experimental run of fifteen days:

SiO_2, 26.9 per cent.

Cu, 18.3 per cent., of which 9.9 was present as CuO.

Fe, 30.0 per cent., of which 17.9 was present as FeO.

S, 9.2 per cent., of which 0.81 was present as SO_3.

The matte formed in crucible fusions contained 65 per cent. copper. In comparing the roasted ore of the MacDougall furnace with that of the Brückner furnace[1] of the same plant, it is found that it is reddish brown as against a dark brown (more Fe_2O_3 is formed), more porous (1 cubit foot weighs 87 pounds as against 100 pounds) and finer (the rolling of the ore in the Brückner cylinder causes particles to form pellets). In regard to flue dust, the MacDougall furnace makes much less than the Brückner cylinder, although the amount is still great; they compare as 1 : 3 to 4.

General Results.—Some of the leading facts of the roasting furnaces operated in Montana are brought together in the subjoined table:

TABLE II.—DETAILS OF MONTANA ROASTING FURNACES.

	Tons Roasted 24 Hours.	Horse Power Required.	Sulphur in Concentrates.	Sulphur in Calcines.	Area of Hearths.	Concentrates per Sq. Ft. Hearth.	Coal per Ton Concentrates.	Cost per Ton.
			Per cent.	Per cent.	Sq. ft.	Lbs.	Lbs.	
Hand reverberatory furnace, 69½ ft. x 16 ft. hearth	13	. .	35	7-8	1,112	12	307	$2.00
Allen-O'Hara furnace, two hearths, 94 ft. x 9 ft.	51	3.64	35	8	1,692	77	145	0.78
Brückner cylinder, 8 ft. x 16 ft.	18-20	1½	37	9.5	. .	. .	540*	1.25
Pearce single-deck furnace	14‡	1½	32	7-8	505	55	400	0.98†
Pearce double-deck furnace, 6-ft. hearths	30‡	3	35	6-7	1,010	59	400	0.98†
Pearce double-deck furnace, 7-ft. hearths	42‡	3	35	6-7	1,218	69	182	0.98†
Keller-Gaylord-Cole furnace, two sets of six hearths	50	1½	38	7-10	2,592	38	67	. .
Wethey furnace, two sets of four hearths, 50 ft. x 5 ft.	60	4	40	8	2,000	60	110	. .
Wethey furnace, two sets of four hearths, 65 ft. x 10 ft.	90	4	35	5-6	2,600	70	80	. .
Herreshoff furnace, five hearths	5-6	. .	35	6	135	80	. .	0.50
MacDougall-Evans-Klepetko furnace, six hearths	40	1½	35	7	952	84	. .	.35
Pearce multiple-hearth furnace, six hearths	56‡	12	35	6-7	2,947	38	28.5	0.98†

* Data obtained from operations of six months at Great Falls. For quality of coal see analysis of Sand Coulee and Belt coal elsewhere in this paper.

† Average.

‡ These low figures are due to the character of the ore (Gagnon mine) which carries 8-12 per cent. zinc.

[1] Size: 8 by 16 feet, one revolution in seven minutes; 15-ton charge in twenty-four hours; drying, two hours; burning, four hours; charging, roasting, and discharging, eighteen hours.

V. Smelting of Ores in the Blast Furnace.

The leading data of the blast furnace practice are brought together in Table III. The furnaces are all of the same general type; they are oblong and water-jacketed, and have an internal crucible which discharges the slag-matte mixture continuously over a raised spout, whereby the blast is trapped. The matte is settled in a large fore-hearth, while the slag overflows, to be granulated and removed by water or to be collected in waste-slag cars and conveyed electrically to the dump and poured.

The general tendency is to increase the size of the furnaces. The smallest distance between tuyères is 42 inches, the largest 56 inches; in one instance it was increased to 72 inches. This worked well with coarse ore, but it proved a failure with the usual run of ores which contain many fines. Thus a screen analysis of an average sample of blast furnace ore from one important mine gave:

300 pounds ore over 2 inches	13.3 per cent.
450 pounds ore 2–1 inches	20.0 per cent.
500 pounds ore 1–$\frac{3}{8}$ inches	22.2 per cent.
1,000 pounds ore under $\frac{3}{8}$ inch	44.5 per cent.
2,250 pounds	100.0 per cent.

showing why such a large distance between tuyères proved impracticable. The greatest length of furnace at tuyères is 180 inches; this seems to be the limit with the present mode of construction of jackets. The height of the furnaces increases with the distances between tuyères from 7 to 18 feet. But the charge in the 18-foot furnace is kept from 4 feet to 8 feet below the throat, so that the actual working height is reduced to from 10 to 14 feet. All furnaces are run with a top more or less hot. Temperature measurements of furnace gases in one instance showed 315° C., and a draught measurement gave a depression 0.8 inch of water. The water jackets are all made of low-carbon steel. They are two-high, reaching to a short distance below the feed door, the remaining space being of brick. There are usually two jackets on a side and one on the ends; the lower tiers of side jackets only have a bosh, the amount of which is very small, while the upper tiers are vertical, as are generally the end jackets. The gases are always drawn off above the feed floor. In one instance the top of the furnace carries a Giroux blast heater, made by the Union Iron Works of San Francisco, which raises the temperature of the blast to 150° C., and at the same time

TABLE III.—EXAMPLES OF MONTANA BLAST FURNACE SMELTING.

FURNACE.	A.	B.	C.	D.	E.	F.
Horizontal section at throat	66 in. x 112 in.	54 in. x 96 in.	72 in. x 180 in.	53 in. x 160 in.	72 in. x 180 in.	72 in. x 180 in.
Horizontal section at tuyères	42 in. x 112 in.	44 in. x 96 in.	56 in. x 180 in.	42 in. x 160 in.	56 in. x 180 in.	56 in. x 180 in.
Area at tuyères	32.66 ft.	29.329 ft.	70.029 ft.	46.629 ft.	70.29 ft.	70.29 ft.
Height, tuyères to throat	7 ft. 3½ in.	9 ft.	18 ft.	10 ft. 6 in.	18 ft.	18 ft.
Height, tuyères to top of crucible	16 in.	9 in.	11 in.	9 in	11 in.	11 in.
Water jackets, height	9 ft.	6 ft.	14 ft. 10 in.	10 ft. 6 in.	14 ft. 10 in.	14 ft. 10 in.
Bosh, inches in feet	12 in. in 6 ft. 4 in.	7 in. in 5 ft.	8 in. in 7 ft.	1 in. in 10 in.§	8 in. in 7 ft.	8 in. in 7 ft.
Crucible, depth	8 in.	16 in.	27 in.	9 to 14 in.	28 in.	28 in.
Forehearth, fixed or movable	Fixed.	Fixed.	Fixed.	Fixed.	Fixed.	Fixed.
Forehearth, shell dimensions	8 ft. x 5½ ft. x 3 ft.	12 ft. di. 52 in. deep.	14 ft. di. 56 in. deep.	7 ft. 3 in. x 10 ft. 6 in. x 4 ft.	14 ft. di. 56 in. deep.	14 ft. di. 56 in. deep.
Tuyères, number	16	12	32	18	32	32
Tuyères, diameter	3 and 3½ in.	2½ in.	3 in.	4 in.	3½ in.	3½ in.
Tuyère ratio*	3.5	2 01	3.23	4 85	3.79	3.79
Blast, pressure, oz.	16†	24	35	30 to 32	28	28
Blast, cu. ft. per ton of ore	57,000	68,574	65,000	. .	. .	60,176 ‖
Blast, temperature, degrees C.	150	15	15	15	15	15
Charge (ore + flux), weight, lbs.	3,300	2,400	2,150	4,000	8,700	10,000
Charge, tons in twenty-four hrs.	125	165	400	220	400	450
Charge, tons per sq. ft. hearth area	3.82	5.56	5 71	4.71	5.71	6.43
Coke, per cent. ash	20.0	21.3	9 to 15	20.0	8.0	8.0
Coke, per cent. of charge	13	12.3	6.1	11.5	9.2	8.5
Men, number in 8-hr. shift‡	5 + 2	4 + 2	3 x 2½	4½ + 3½	3 +	4 +
Matte, per cent. of charge	. .	5.1	. .	. .	. .	5.5
Matte, Cu per cent.	50	46	49	38	42	42.12
Zn per cent.	. .	. .	1.0	. .	. .	. .
Ag oz.	69	52	20	. .	. .	. .
Au $	2	10	. .	. .	. .	. .
Sp. gr.	. .	. .	5.0 to 5.1	. .	. .	4.8
Slag, SiO_2	47.7	44.3	40.7	48.0	40.0	42.6
Fe(Mn)O	18.5	27.0	26.2	17.0	23.0	30.7
Ca(Mg)O	28.2	23.0	19.4	20.0	22.6	19.5
Al_2O_3	. .	9.0	9.6	6.0	9.8	. .
Cu	0.35	0.32	0.25	0.30	0.30	0.25
Ag	0.43	0.30	. .	. .	0.20	. .
Sp. gr.	. .	. .	3.0 to 3.55	. .	. .	3.3

* Sq. in. tuyère area : 1 sq. ft. hearth area.

† Estimated at 50 per cent. of the rated capacity of the blowers.

‡ First figure represents the regular crew ; second figure auxiliary labor.

§ Lower jackets only.

‖ Ore-flux.

acts as a dust catcher, delivering the saved dust back into the blast furnace. The charge in most works is introduced by hand from the sides of the furnace; occasionally it is fed from the ends. In some instances, with large furnaces putting through 400 tons charge in twenty-four hours, mechanical feeding has taken the place of hand feeding. The charge is brought by electric or compressed-air traction to the side of the furnace on trucks with tilting carriages; the doors are raised by compressed air, and the charges slid in alternately from one side and the other. This method seems to be satisfactory. At least, worked out in one large plant, it has been introduced in another with some improvements in the construction of the carriage. While it is generally maintained, and has recently been again emphasized by P. Johnson[1] in connection with copper smelting, that the successful working of a blast furnace is much governed by the care given to feeding, it must be admitted that, considering the mechanical feeding practiced at Butte with copper ores producing siliceous slags high in lime, and at Pueblo, Colorado,[2] Murray, Utah,[3] East Helena, Montana,[4] with lead ores, where blow holes or uneven sinking of charges must be absolutely avoided, hand feeding cannot hold its former monopoly, but will have to yield to mechanical devices.

The hearth in some plants is supported by jackscrews; in others it is built up solid from the foundations. It rises some distance above the furnace floor in order to furnish the height necessary for the forehearth or settler and the disposal of the waste slag. The hearth is lined to a depth of from 24 to 30 inches with fire brick, or only with one or two courses of fire brick, and then with a mixture of quartz and clay. The crucibles have a depth varying from 8 to 28 inches. Although deep crucibles last rarely longer than three months and shallow crucibles have a longer life, the former are more common. Preliminary experiments with lining deep crucibles with chrome brick[5] have given promising results in preventing breakouts of matte. There appears to be no *a priori* reason for having a continuously discharging crucible as

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[1] *Engineering and Mining Journal*, Aug. 23, 1902.

[2] Hofman, *Metallurgy of Lead*, 1901, p. 216; *Transactions American Institute of Mining Engineers*, November, 1901.

[3] *Engineering and Mining Journal*, June 28, 1902.

[4] *Transactions American Institute of Mining Engineers*, November, 1901.

[5] Lang, *Engineering and Mining Journal*, Jan. 23, 1897. Packard, *Engineering and Mining Journal*, Feb. 13, 1897. Glenn, *Transactions American Institute of Mining Engineers*, XXXI, p. 374.

deep as 28 inches; 8 to 10 inches would seem to be sufficient to furnish the matte bath necessary to cover the bottom satisfactorily, but this is disputed by the best of authority. In treating zinckose ores the deep crucible would probably soon fill up with mushy matte and cause infinite trouble, but the ores smelted fortunately contain very little zinc.

It is claimed that with a deep crucible a furnace puts through more charges, but this has so far not been proved. As far as the strength of the jackets is concerned, the deep crucible is preferable, as with a shallow crucible the tuyères are located higher up (viz., 24 and 12 inches; see table) in order to furnish a smelting zone of some height, and the water-cooled breast has to be built into the jacket; while with the deep crucible it is placed underneath the jacket.

The slag-matte mixture is usually discharged from the centre of one of the sides of a furnace. The water-cooled tymp is made of cast iron or, preferably, of copper. Experiments with copper and copper alloys gave the following data:

Life, Days.	Cu. Per Cent.	Zn. Per Cent.	Al. Per Cent.	P. Per Cent.	Sn. Per Cent.
365	100	. .	. .	Some.	. .
144	90	. .	0.5	. .	10
75	89	3.0	0.25	. .	8

The solid cast-iron spout with water-cooled nose is very common; wrought-iron pipe surrounded by cast iron has proved unsatisfactory; a water-cooled wrought-iron spout with a cast-copper removable nose lasts about 120 days, and is often preferred to cast iron.

The tuyère-stock in common use consists of a cast-iron tuyère-box firmly attached to the jacket, and connected by a sheet-iron tuyère-pipe having a gate with the bustle pipe.

The large size of the roofless forehearth in which the matte settles out from the overflowing slag is a development of Montana practice, caused by the necessity of storing considerable quantity of liquid matte for the converters. As far as the settling of matte is concerned, oval and oblong hearths are sufficient, as the freedom of copper in waste slag depends to a large extent upon the length of the path the slag can travel before it overflows. In regard to storage capacity and strength of vessel the circular hearth is preferable, hence it is only with a comparatively small blast furnace not furnishing direct matte that we find

the oval or oblong forehearth. The circular forehearth, 14 feet in diameter and 56 inches high, with a 9-inch brick lining and a 9-inch brasque backing, holds about 60 tons of matte when new. In order to prevent breaking out, the shell is sprayed with water. After being about three months in use, its capacity has so decreased by building that it becomes necessary to renew it. The 9-inch course of brick sometimes has a 3-inch backing of sand, which seems to be sufficient. The smaller oblong hearth has, as a rule, cast-iron water jackets on the sides; it has a 9-inch bottom, which crusts up about 6 inches; the sides are lined with a half-course of brick, a 1-inch air space being left at the water jacket. All forehearths have, of course, a tapping slot for matte. It is closed in a few instances by a cast-iron plate, but more commonly by a solid copper plate with tap hole. The matte is tapped from the forehearth into a ladle, which discharges its contents either into flat cast-iron moulds holding about 3,000 pounds, or into the converter. The practice of bringing the converter to the forehearth of the blast furnace has become obsolete. The blast-furnace forehearth, if of large size, is of great assistance to the reverberatory matting furnaces in a plant which converts matte, as it makes little difference whether the forehearth contains much or little matte; it can be allowed to fill to near the top, or it can be tapped nearly dry. With the reverberatory furnace this is not the case. The aim there is to allow the level of the matte to fluctuate as little up and down as possible. This means that only a certain quantity of matte can be tapped at stated intervals. If, therefore, the converter calls for matte and the reverberatory furnace can furnish only an insufficient amount, there is the blast-furnace forehearth, forming a kind of balance wheel, to help over the difficulty. The waste slag is caught in tilting waste-slag pots of from 5 to 6 tons capacity, and hauled to the dump, or it is granulated. Near the bottom of the launder carrying the slag granules there is found often a mechanical sampler, driven by the granulating water, which takes out the whole of the stream of granules at stated intervals, and thus furnishes a true sample of all waste slag made.

Coke. — The coke used around Butte comes from different parts of the country, as shown by the following table; most of it, however, is made from Montana coal:

TABLE IV.—AVERAGE COKE ANALYSES.

YEAR.	TOTAL H_2O.	H_2O.	VOLATILE MATTER.	FIXED CARBON.	ASH.	SP. GR.
Lehigh, Pennsylvania:						
1897	. .	0.3	1.3	85 7	12.6	. .
1898	. .	0.5	3.2	82.7	13.4	. .
1899	. .	0.4	3.9	81.0	14.6	. .
1900	0.6	0.2	4.2	81.8	13.8	. .
1901	0.3	0.2	3.6	84.2	12.2	. .
Total	0.9	1.6	16.2	415.4	66.6	. .
Average	0.4	0.3	3.2	83.1	13.3	. .
Horr, Montana:						
1899	. .	0.5	4.2	75.2	20.3	. .
1900	. .	0.3	4.0	75.7	19.9	. .
Total	. .	0.8	8.2	150.9	40.2	. .
Average	. .	0.4	4.1	75.4	20.1	. .
Crow's Nest, British Columbia:						
1900	0.5	0.2	4.1	85.8	9.9	. .
1901	0.3	0.2	3.3	85.3	10.7	. .
1902	. .	0.2	4.7	84.5	10.5	. .
Total	0.8	0.6	12.1	255.6	31.1	. .
Average	0.4	0.2	4.0	85.2	10.3	. .
Belt, Montana:						
1899	. .	2.3	4.7	79.3	13.7	. .
1902	. .	0.3	3.6	83.0	12.4	1 45
Total	. .	2.6	8.3	162.3	26.1	. .
Average	. .	1.2	4.2	81.1	13.0	. .
Cardiff, Colorado:						
1902	. .	0.4	3.6	85.7	10.3	2.45
West Superior, Wisconsin:						
1902	. .	0.3	3.7	81.4	14 5	. .
Fairmount, West Virginia:						
1902	0.1	0.1	4.5	82.4	13.0	. .
Castle Gate, Utah:						
1902	. .	0.2	3.5	86.1	10.2	. .

TABLE V.— ANALYSES OF COKE ASH.

SOURCE.	KIND.	SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	S.
Montana	Horr	57.0	19.0	21.2	3.3	. .	. .
Montana	Belt	51.6	10.0	33.6	. .	. .	. .
Colorado	Cardiff	48.9	18 9	23.9	5.8	1.4	0.8

In the management of a blast furnace the tendency has been toward large tonnages, with the production of 50-per cent. copper matte, and slag low enough in copper to be a waste product. Tonnage had to contend with siliceous ores low in iron and with limestone as the only available flux, which caused the making of slags of high melting temperatures. As, further, large amounts of limestone are required to make slags that are at all fusible, the formation temperatures lie higher than when there is a more intimate contact of acid and base. Tonnage was therefore obtained mainly by increasing the size of the furnace, as shown in the preceding table. The combination of siliceous slags low in iron, with much air, has been the cause of as much as 70 per cent. of the sulphur in the charge being burnt off in its descent through the furnace. But even with the large elimination of sulphur in a comparatively dense charge, it is often not possible to obtain the 50-per cent. matte desired for the converter plant; hence blast-furnace matte is sometimes tapped from the forehearth into a ladle, and poured into the reverberatory matting furnace to raise the percentage of copper by mixing with higher-grade matte. Table VI gives in percentages some idea of how the charges are made up.

Table VII shows partial analyses of flue dust and briquettes, giving an idea of their general character.

The briquetting machines of Chisholm, Boyd and White (Chicago), and of H. S. Mould (Pittsburg) are both used.

VI. SMELTING OF ORES IN REVERBERATORY MATTING FURNACE.

The leading facts of the reverberatory furnace practice are brought together in Table VIII.

The characteristics of Montana reverberatory matting furnaces are the form of hearth and the greatness of its area. While as late as 1891 the hearth had the usual pear-shaped form of the original Welsh

TABLE VI.—Percentage of Components of Charge.

Plant.	First-class Ore.	Coarse Concentrates.	Matte.*	Converter Slag.†	Briquettes.‡	Limestone.	Coke.
A	22.4	20.5	4.0	17.8	4.0	22.8	8.5
B	52.5	. .	2.3	8.9	. .	25.6	10.7
C	15.5	25.0	22.5		0.2	27.6	9.2

* The matte comes in part from the reverberatory matting furnace, which had to be tapped when the converter plant was not ready. In part it is purchased matte to be remelted for the converter.

† The converter slag always goes to the blast furnaces, as it furnishes coarse material, aids the smelting in having been already once smelted, and acts as a basic flux (see Analyses below). Experience has shown that it not only does little good in the reverberatory matting furnaces, but that it does harm in that it increases the amount of slag to be skimmed, and reverberatory-furnace slags run higher in copper than blast-furnace slags.

‡ The briquettes are a mixture of flue dust with 3 to 4 per cent. slacked lime; sometimes slimes from the ore dressing works are added to replace the lime.

TABLE VII.—Analyses of Flue Dust and Briquettes.

Flue dust from	Cu.			SiO_2.	Fe.	Al_2O_3.	CaO.	S.		As and Sb.	Ag, oz. per Ton.
	Total.	Sol. in H_2O.	Sol. in H_2SO_4.					Total.	Sol. in HCl.		
Flue near MacDougall furnace	13.3	. .	. .	47.9	11.9	. .	. .	12.0	. .	. .	4.2
MacDougall furnace	11.8	. .	. .	52.0	11.0	. .	. .	7.9	. .	. .	4.8
Blast furnace	10.6	. .	. .	33 2	18.7	. .	. .	10.7	. .	. .	5.3
Blast furnace	10.4	4.2	5.7	26.5	13.9	37.7	4.2	7.3	5.3	1.6	. .
Blast furnace	12.85	. .	. .	34.8	16.3	. .	. .	13.3	. .	. .	. .
Dust chamber	13.3	1.6	5.4	31.7	8.3	15.8	0.5	7.6	. .	9.1	. .
Dust chamber	7.2	. .	. .	34.3	11.9	13.3	. .	7.27	. .	. .	3.4
Stack	. .	. .	. .	. .	. .	. .	. .	. .	. .	14.3	. .
	6.3	. .	. .	40.0	20.8	. .	. .	9.3	. .	. .	54.0
Briquettes (dust and slimes)	6.5	. .	. .	63.0	13.0	5 3	. .	8.0	. .	. .	. .
Briquettes (dust)	12.5	MgO. 0.8	H_2O. 13.05	36.0	13.9	11.0	2.7	8.96	Insol. 45.6	0.66	5.0

furnace (Figure 1), a radical change was then inaugurated by making the hearth oblong, tapering very quickly toward the bridge, but less so toward the flue (Figure 2). The result was an enlarged hearth area served by the same grate area which, on account of the free development of the flame, could heat more effectively and smelt a larger amount of charge per unit of fuel consumption than with the old form. While at Argo, Colorado,[1] the reverberatory matting furnace of

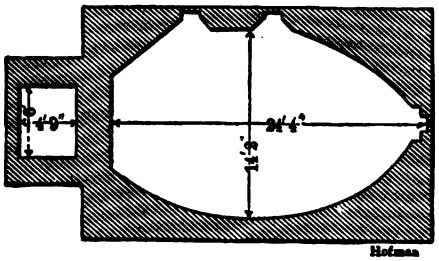

FIG. 1.

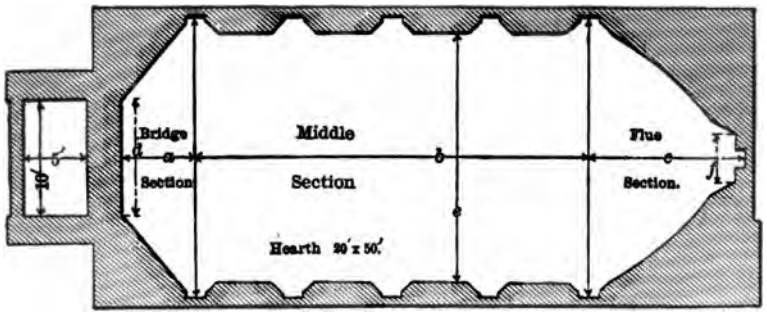

FIG. 2.

1878 had a hearth area of 105 square feet, with a ratio of hearth-to-grate area as 4.66 : 1; in 1894 the hearth area had been increased to 481 square feet and the ratio to grate area decreased to 15.03 : 1. At present the Montana furnaces reach in round figures a hearth area of 880 square feet, with hearths 50 feet long and 20 feet wide (in the middle section, Figure 2); the ratio of hearth-to-grate area differs, however, only slightly from the Argo standard of 1894. Such a furnace treats 105 tons of charge in twenty-four hours, producing 50-per cent. matte with a concentration of three to four into one. These large furnaces have many advantages over the smaller ones besides the greater

[1] Peters, *Modern Copper Smelting*, 1895, p. 445.

TABLE VIII.—Examples of Montana Reverberatory Furnace Smelting.

	A.	B.	C.	D.	E.	F.
Length of hearth	50 ft.	50 ft.	49 ft. 6 in.	50 ft.	42 ft. 6 in.	37 ft.
Length, *a*, of bridge section*	6 ft.	6 ft.	4 ft. 6 in.	6 ft.	42 ft. 6 in.†	. .
Length, *b*, of middle section*	28 ft.	32 ft.	32 ft.	32 ft.	42 ft. 6 in.†	16 ft.
Length, *c*, of flue section*	16 ft.	12 ft.	13 ft. 0 in.	12 ft.	42 ft. 6 in.†	. .
Width, *d*, of hearth at bridge*	10 ft.	10 ft.	10 ft. 9 in.	10 ft. 9 in.	15 ft. 9 in.	8 ft. 0 in.
Width, *e*, of hearth at middle*	20 ft.	20 ft.	20 ft. 2 in.	20 ft.	15 ft. 9 in.	14 ft. 6 in.
Width, *f*, of hearth at flue*	4 ft.	6 ft.	4 ft.	4 ft.	15 ft. 9 in.	5 ft. 0 in.
Hearth area, sq. ft.	842	886	878	878	688	. .
Hearth, thickness	22 in.	24 in.	19 in.	20 in.	28 in.	22 in.
Length of grate	10 ft.	10 ft.	7 ft.	10 ft. 9 in.	Producer gas, regenerative chambers	8 ft.
Width of grate	5 ft. 5½ in.	5 ft. 4 in.	5 ft. 6 in.	5 ft.		6 ft.
Depth of grate below top of bridge at bridge	1 ft. 10 in.	2 ft. 9½ in.	2 ft. 4 in.	2 ft. 8 in.		3 ft. 0 in.
Depth of grate at opposite end	1 ft. 2 in.	2 ft. 6¼ in.	1 ft. 4 in.	2 ft. 2 in.		. .
Grate area, sq. ft.	53.9	53.3	53.0	53.75		48.0
Ratio, hearth : grate area	15.6	16.6	16.5	16.3		. .
Height of roof above bridge	2 ft. 7 in.	2 ft. 6½ in.	2 ft. 10 in.	2 ft. 8¾ in.	24 in.	2 ft. 0 in.
Height of roof above hearth at bridge	4 ft. 8 in.	4 ft. 4 in.	4 ft. 4 in.	4 ft. 8 in.	7 ft. 0 in.	4 ft. 10 in.
Height of roof above hearth at flue	2 ft. 1½ in.	2 ft. 10 in.	3 ft. 0 in.	2 ft. 2 in.	. .	2 ft. 4 in. to 2 ft. 8 in.
Width of bridge	3 ft. 0 in.	3 ft. 5½ in.	3 ft. 0 in.	3 ft. 0 in.	4 ft. 1½ in.	. .
Size of flue at vulcatory	6 ft. x 30 in.	6 ft. x 30 in.	5 ft. x 30 in.	6 ft. x 30 in.	. .	36 in. x 6 ft. 6 in. to 7 in.
Size of flue leading to chimney	30 in. x 48 in.	30 in. x 30 in.	28 in. x 30 in.	30 in. x 30 in.	42 in. diam. at each end	30 in. x 36 in.
Chimney, inside diameter	5 ft. 6 in.	6 ft. 3 in.	6 ft. 0 in.	6 ft. 1 in.	. .	4 ft. 6 in. x 4 ft. 6 in.
Chimney, height	70 ft.	. .	70 ft.	75 ft. 3½ in.	. .	80 ft.

* See Fig. 2.

† The hearth has the form of a rectangle.

TABLE VIII.—EXAMPLES OF MONTANA REVERBERATORY FURNACE SMELTING. (*Continued.*)

	A.	B.	C.	D.	E.	F.
Charge, weight, tons	25	15	24	18	35	13
Charge, time of melting, hours	5	3½	6½	4½	6	5½
Charge, tons in twenty-four hours	112.5	105	90	90	150	70
Charge, tons per sq. ft. hearth in twenty-four hours	0.129	0.118	.102	0.102	0.218	. .
Rate of concentration	5.7 : 1	4.7 : 1	7.56 : 1	5 : 1	3½ : 1	5 : 1
Fuel, bituminous coal, manner of firing	Direct	Direct	Direct	Direct	Producer gas	Direct
Fuel, bituminous coal, per cent. ash	8.9	15.0	14.85	5.0	17.0–30.0	7–10
Fuel, bituminous coal, per cent. fixed carbon	51.9	44.5	44.5	55.0	45.0	50–52
Tons charge : 1 ton coal	3.05	3 : 1	4 : 1	2.81 : 1	2 : 1	2.5 : 1
Labor, in eight-hour shift*	2+2	2+2	2+2½	2½+1½†	†	2½+1½
Matte, Cu	53.8	48.3	50	50	50	55
Ag ozs. per ton	45	35	100	66	20	. .
Au $ per ton	. .	. .	. .	2(?)	. .	. .
Sp. gr.	. .	4.8	. .	. .	4.77	. .
Slag, SiO_2	36.8	42.8	34.5	38.6	41.9	46
Fe(Mn)O	51.9	47.31	43.0	51.4	42.7	32–36
Al_2O_3	8.4	7.5–8.0	8.5	1.5	10.9	. .
ZnO	. .	. .	14.0	. .	. .	. .
CaO	1.1	1.2	. .	3.3	1.1	. .
Cu	0.75	0.40	0.60	0.40	0.58	0.65
Ag	0.45	0.30	1.0	0.40	. .	. .
Sp. gr.	. .	3.58	. .	. .	3.54	. .

* The first figure represents the regular crew, the second the auxiliary labor.
† Not comparable in this manner on account of gas producers.

capacity. The sides are less readily corroded by the slag (claying every twelve days versus every three days), as for a given amount of matte less surface is exposed to the slag; there is less variation in temperature on account of the greater reservoir of heat, which lengthens the life of the brick; the layer of slag is thinner, which allows quicker heating and causes less foaming when the charge is dropped from the hoppers; and the level of the matte remains more constant.

Fuel. — The fuel used is bituminous coal of various grades from Montana, Wyoming, and Utah, some of which are represented in Table IX.

TABLE IX.— AVERAGE COAL ANALYSES.

Further analyses of coals are given in the Appendix, Table XV.

LOCALITY AND STATE.	NAME OF MINE.	KIND OF COAL.	YEARS AVERAGED.	H_2O PER CENT.	VOLATILE MATTER.	FIXED CARBON.	ASH.
Belt, Montana	Belt	Slack	1898–'99–1902	1.6	30.4	45.7	22 3
	Belt	Washed slack	1899–1900	0.8	33.0	49.2	17.0
	Belt	No. 1 nut	1900	0.2	38.1	47.2	14.5
	Belt	Pea	1900	0.8	33.4	48.9	16.9
	Belt	Washed pea	1900	0.9	35.3	50.5	13.3
	Belt	Washed nut	1901–1902	1 3	29.2	50.2	19.3
	Belt	Lump	1900–1901	1.5	29.3	50.8	18.4
	Belt	Lump	(?)	2.2	24.25	46.65	26.9
	Belt	Lump	(?)	2.4	22.1	43.2	32.2
	Belt	Mine run	1901	0.9	27.6	47.3	24.2
	Belt	Mine run	(?)	3.9	24.9	49.6	24.6*
Stockett, Montana	Sand Coulee	Slack	1898–1900	1.2	30.8	46.1	21.9
	Sand Coulee	Washed nut	1898–1901	1.4	31.8	50.4	16.4
	Sand Coulee	Mine run	1899	1.1	28.1	46.2	24.6
	Sand Coulee	Nut	1898–1900	1.1	30.3	45.8	22.8
	Sand Coulee	Lump	1900–1901	0.9	30.4	50.2	18.5
	Cottonwood	Slack	1898–1901	1.1	30.1	44.3	24.5
	Cottonwood	Nut	1898–1901	1.1	29.7	44.7	24.5
	Cottonwood	Lump	1899–1901	0.8	30.4	46.3	22.5
Sand Coulee, Montana	Lochray	Lump	1899–1901	1.6	30.2	47.3	20 9
	Lochray	Mine run	1899–1901	1.0	30.0	47.7	21.3
	Lochray	. .	. .	1.8	27.4	52.1	19.4
	Gerber	Lump	1900–1901	0.9	31.2	48.9	19.0
	Gerber	Mine run	1899	1.2	31.5	48.5	18.8
	Gerber	. .	. .	1.0	23.5	56.7	17.7
	Millard	Slack	1899	0.5	33.2	45.6	20.7
	Millard	Mine run	1899–1900	0.8	31.1	46.7	21.4
	Lewis	Slack	1898–1899	1.2	31.7	45.9	21.2
	Lewis	Lump	1898–1901	0.9	30.4	49.0	19.7
	Lewis	Mine run	1899–1900	1.0	30.5	46.6	21.9
Wyoming	Sweet Water	. .	1902	4.6	32.0	56.4	7.0
	Sweet Water	. .	1902	5.4	31.8	50.4	12.0
	Bear Creek	. .	1902	7.85	36.45	46.65	9.05
	Diamondville	Slack	1902	2.6	37.58	45.12	14.70
	Diamond	Lump	1902	4.7	36.52	44.56	14.85
Utah	Gas coal †	. .	1902	4.8	33.0	59.1	1.9
British Columbia	Lethbridge	Slack	1898–1901	2.5	31.5	43.9	22.1
	Lethbridge	Nut	1898	4.3	31.6	45.0	18.8
	Lethbridge	Pea	1899	2.9	34.6	41.2	21.3
Pennsylvania	Anthracite	. .	1900–1901	0.5	7.8	80.6	11.1

* Average of ten months. † S 1.2 per cent.

Most furnaces are direct fired. Some furnaces are worked with natural draft, but the majority have undergrate blast. In one instance the original fire box has been changed to receive a Duff (Pittsburg) gas producer, with most satisfactory results as to saving of fuel and to shortening of the time required for melting. This latter is due to the fact that the ordinary grate has to be cleaned every four hours, while the grate of the Duff producer requires attention only once in twenty-four hours. On account of structural difficulties the producer had to be given up. In many furnaces air is admitted through the roof above the fire bridge in order to secure a better combustion and thereby save fuel. The air[1] travels through the vault underneath the furnace, rises some distance in two corners of the stack (square on the outside, circular on the inside), descends in the others, returns underneath the hearth through three or four horizontal channels on either side of the vault, rises in corresponding vertical boxes near the bridge, enters both sides of an air chamber on the roof above the bridge, and descends through slots into the fire-bridge flue. There is some doubt prevalent as to the efficiency of this superheating. With most furnaces the heat of the flame passing out of the furnace goes to waste. According to Hixon[2] attempts had been made to join the Brown-Allen-O'Hara roasting furnace to a reverberatory matting furnace, but without success, owing to mechanical difficulties. Hixon suggests improvements which are to overcome them. Lang[3] patented a combination of reverberatory matting furnace with a hand reverberatory roaster; at Kedabeg, in the Caucasus, such a combination is said to be[4] in successful operation. Attempts have been made by Thum[5] to combine the Belgian zinc-smelting furnace with a hand reverberatory roasting furnace for roasting blende, but without success. The main difficulty would seem to lie in the fact that, in order to roast successfully in a reverberatory furnace, it is essential to have a steady even temperature at the fire bridge, and with a reverberatory matting furnace, charged and discharged at intervals, this is not easily obtained, if it can be managed at all. In order to utilize the waste heat, one Montana plant has attached a 300-horse power Stirling boiler, Class A, $2\frac{1}{2}$, with 3,019

[1] See also Peters, *op. cit.*, p. 456.

[2] *Notes on Lead and Copper Smelting*, New York, 1897, p. 59.

[3] *Engineering and Mining Journal*, Aug. 6, 1898.

[4] *Berg- und Hüttenmännische Zeitung*, 1891, p. 449; *The Mineral Industry*, VI, p. 247.

[5] *Berg- und Hüttenmännische Zeitung*, 1874, p. 276.

square feet heating surface to one of its 50- by 20-foot furnaces. While an attempt of this kind in an Eastern refinery had proved a failure, owing to the diminished melting power caused by the reduced force of the draught, here it proved an unequivocal success. At first, when the boiler was set up in the usual way, the smelting power of the furnace was reduced to an unreasonable figure, which was restored by removing nearly all the baffle plates and thus giving the gases a straight course through the boiler.

One plant only has reverberatory matting furnaces with regenerative chambers similar to the open-hearth steel furnaces with stationary hearths. Tilting furnaces (hearths 13 by 16 feet with 176 square feet area), similar to the Campbell open-hearth steel furnace,[1] which were built in 1890 and 1892, were abandoned on account of their small capacity, and because of the fact that it was impossible, in pouring off the slag, to control the flow in such a manner as to prevent matte from passing over. Small amounts of matte in a large mass of slag cannot be distinguished by the eye. These furnaces were run, however, for several years as stationary furnaces, being gradually replaced by furnaces of larger size. The gas producer used is the Evans-Klepetko;[2] it is a modification of the well-known Taylor producer, is 15 feet high, has a 7-foot bosh and a throat 7 feet 4 inches in diameter. The points in which it differs from the Taylor producer are a revolving top, a mechanical feed discharging into a hopper in the centre of the top, a steam-jet reaching into the hopper, which, with a pressure equal to that of the gas in the furnace, prevents this gas rising through the coal; four water-cooled stirring-arms attached to the revolving top which reach down into the bosh and are so distributed that they cover the entire surface during one revolution; lastly, an attachment for the sluicing of ashes as they are discharged by the revolving grate. The producer gasifies from 10 to 12.5 tons coal in twenty-four hours, the top making one revolution in three minutes. The analyses in Table X give a comparison of the two kinds of coal used and of the ashes formed.

Details of Practice. — The coal is crushed through a $\frac{3}{4}$-inch ring and passed through a 5-millimeter screen; the oversize goes to the producers; the fines, forming about 30 per cent., are burned under the boilers. It will be seen that, owing to the high percentage of ash in the coal, the amount of fixed carbon retained by it is exceedingly high. The

[1] *Transactions American Institute of Mining Engineers*, XXII, p. 360.

[2] *United States Patent*, No. 704,527, July, 1902.

flue from the six producers serving one matting furnace has to be fired once in eight days to remove soot, tar, etc., and washed out once in six weeks to free it from ashes. An average analysis of producer gas taken from a large number of determinations gave CO_2, 9.4; CO, 16.8; CH_4, 2.9; H, 13.3; N, 57.6. The high percentage of carbon dioxide is probably due to the excessive use of steam. Bunte[1] has shown that the larger amount of steam that is admitted to a producer the larger is the volume of carbon dioxide formed. The gases, however, pass off from the producers with a temperature of 700° C., which would seem to counteract the cooling effect of the steam, and cause the carbon to burn rather to carbon monoxide than to dioxide.

The hearth of the regenerative matting furnace, 42 feet 6 inches by 15 feet 9 inches, has the same width at the ends as at the middle. While this arrangement gives a larger hearth area than in the furnace tapering at the ends, it has the disadvantage that the sides tend to bulge inwardly instead of outwardly, as is ordinarily the case. The furnace is built in five sections in order to allow for expansion, which amounts to 14 inches over all. The sections are separate in the roof; in the 18-inch side-walls the necessary spaces are left between the bricks. The upper tie rods run over 1 foot above the roof (from 9 to 12 inches thick), as this may rise as much as 9 inches; the lower tie rods, placed 4 feet below the brick hearth supporting the quartz bottom, were passed at first through 4-inch wrought-iron tubes; when these burned out the new tie rods were provided with a small central opening for water cooling. At present the rods are solid, $1\frac{1}{2}$ inches in diameter, and pass through a flue 2 feet 6 inches by 3 feet 8 inches, which is ample for air cooling. The checker work has a peculiar construction to permit cleaning, and thus reduce the slagging of the brick through dust. The flues are horizontal, 18 inches high by 7 inches wide by 11 to 21 feet long, according to position; they are constructed of fire brick. The 9-inch brick forming the tops and bottoms are laid $4\frac{1}{2}$ inches apart, leaving open spaces to allow the dust to fall and collect in a pit at the bottom, from 4 to 5 feet deep. The heating surface is not very much diminished by this arrangement, as the sides of the horizontal bricks are exposed to the hot gases; this would not be the case if the bottoms and tops did not have the open spaces. The dimensions of the air chambers are: width 8 feet 6 inches by length 14 feet $7\frac{1}{2}$ inches by height 13 feet 9 inches; of the gas chambers, width 7 feet by length

[1] Ledebur, *Gasfeuerungen*, Leipsic, 1891, p. 34.

TABLE X.—ANALYSES OF PRODUCER COAL AND ASH.

Coal.*					Ash.†			
Total H_2O.	Comb. H_2O.	Volatile Matter.	Fixed Carbon.	Ash.	H_2O.	Volatile Matter.	Fixed Carbon.	Ash.
Mine Run of the A. C. M. Company Belt, Montana.								
4.0	1.0	23.6	51.3	24.1	1.1	10.4	45.4	43.1
4.7	1.8	21.4	48.4	28.4	1.4	3.3	34.3	61.0
4.4	1.4	24.4	49.3	24.9	1.5	4.3	30.4	63.0
4.1	1.4	25.4	48.8	24.4	0.9	12.3	40.5	46.3
4.2	1.4	23.9	46.9	27.8	1.6	4.6	36.3	57.5
4.1	1.4	25.5	49.9	33.2	1 2	9.6	24.1	70.1
Mine Run of Lochray Mine, Sand Coulee, Montana.*								
5.0	0.9	27.5	51.7	19.9	0.3	2.4	36.4	60.9
4.4	1.1	26.3	52.6	20.0	0.2	3.0	13.9	82.9
4.5	0.8	27.0	50.7	21.5	0.3	3.2	24.3	72.2
3.8	0.7	27.3	52.7	19.5	0.3	3.8	24.1	71.8
Mine Run of Gerber and Lochray Mines.								
					0.3	7.0	32.5	60.3

* For heat values of these and of other coals, see Appendix, Table XV.

† Not to be depended upon too much on account of difficulty of obtaining a good average sample.

The Anaconda coal alone does not work well in the producer; it is added to the Lochray coal, which alone gives very satisfactory results.

The ash from the Gerber-Lochray coal, freed from carbon, shows the following composition:

SiO_2, 44.15; Fe_2O_3, 16.6; Al_2O_3, 37.9; CaO, 1.0; MgO, 0.4; S, 0.04.

14 feet $7\frac{1}{2}$ inches by height 13 feet 9 inches. The heating surfaces, including exposed walls, are 4,900 and 4,200 square feet, respectively. While long checkers save fuel, they tend to shorten campaigns; the reverse is the case with the short checkers. Air enters the hearth through a single port 15 feet 9 inches by 2 feet; the gas through four ports $20\frac{1}{4}$ by 30 inches. The products of combustion from the furnace descend in a chamber at one end of the checkers, and after passing through these, ascend in the other at the opposite end. The life of the

checkers is about three months. In order to lengthen it, experiments are under way to have the gases go, during the charging period, through a by-pass direct into the main flue, and thus prevent the inevitable dust from settling in the checker flues.

The working-bottoms of the furnaces, as shown in the table, have a thickness ranging from 19 to 28 inches at the lowest point, the tap-hole. Both single- and double-bottoms are found. The single bottom is more common with ore smelting, as here the furnace has to carry a relatively light material in comparison with the refining furnace with which the double bottom is more prevalent. The bottom-sand is a sugar-like quartzite, with 95 per cent. silica, the rest being alumina and ferric oxide. It is crushed between rolls to bean-size, say through a $\frac{1}{4}$-inch ring; 80 per cent. of it will pass through a 5-millimeter screen. Two examples of putting in a bottom will show how great are the differences in practice. One furnace has a hearth 20 by 50 feet, is direct-fired, and takes 73 tons of crushed sandstone. Supposing the furnace to be dry and warm, from 6 to 7 tons of sand are charged and heated for 6 hours, being rabbled at intervals. These operations are continued until one-half of the total sand required has been introduced, when the whole is heated to the fritting of the surface. The other half of the sand is now charged in the same manner as was the first, and brought to fritting. Converter slag is now poured in to cement the particles of sand more firmly together; from three to four charges of calcines are worked, and the furnace tapped dry after the fourth charge. The furnace is allowed to cool for three to four hours, and is ready for regular work. The time required for putting in the bottom is four days. The bottom under consideration was put in in February, 1900, and shows little wear today (June, 1902).

The other extreme is represented by a gas-fired furnace with regenerative chambers; the rectangular hearth is 42 feet 6 inches by 15 feet 9 inches. It is presupposed that the furnace is new and requires drying and warming. A light wood fire is started on the hearth in half a dozen places; the valves are reversed every half hour. In ten days the furnace will be at a dull red; in two days more it will be hot enough to ignite producer gas. The gas is turned on in small amount at first; after three days the wood ashes are taken out; on the fourth or fifth day (the sixteenth or seventeenth after starting) the furnace will be a bright cherry red. Five tons sand are charged through the hoppers in the roof and spread; they cover the hearth to a thickness of

2 inches. The sand is calcined, turned over, and the furnace brought to a normal heat; charging of sand and heating it are continued in five- to six-hour intervals until about 60 tons have been introduced, care being taken to have the sand thoroughly calcined. The furnace is now brought in from thirty-six to forty-eight hours to the highest heat that can be obtained without endangering the brickwork, and the sand brought to a set which amounts to about 3 inches in thickness. The high heat is maintained for sixteen hours, and the furnace then cooled down in eight hours to a dull cherry red. Enough calcines (giving 45-per cent. copper matte) are dropped through the roof to cover the hearth to a depth of 3 inches; they are melted down and are absorbed by the sand bottom. The furnace is cooled as before, and a second charge of calcines given and smelted. Part only of the charge will be taken up by the hearth; the rest is tapped out. The furnace is again cooled, from 12 to 15 tons ore-charge are given, melted down, and the furnace tapped dry and cooled to a dark red, but more slowly than before. It is again fired up, worked for three days as under normal conditions, and then tapped dry and allowed to cool to a cherry red. It is now safe for any kind of work. The time required to bring a new, cold furnace to this point is three weeks. The object of the repeated coolings of the furnace is to harden the bottom. A bottom put down without cooling is liable to be mushy when it is hot, even though it be hard when relatively cool.

The ore-charges consist mainly of roasted concentrates, with fines from first-class ore; sometimes small additions of limestone are made. In converter plants low-grade blast-furnace matte is often poured into the reverberatory matting furnace in order to raise the percentage of copper.

In regular work the charge is collected above the furnace in from five to seven hoppers, having discharge pipes with gates, and dropped onto the hearth. With non-regenerative furnaces the bulk of the charge is collected near the fire bridge; thus with five hoppers, *e.g.*, seven and one-half volumes of the charge will be dropped through hopper Number 1 near the fire bridge, then six and one-half volumes through hopper Number 2, five through Number 3, three through Number 4, and one through Number 5 near the flue bridge. With a regenerative furnace having, for example, seven hoppers, charge will be first dropped through the end hoppers that it may flow toward the centre, then through the central hopper and its two neighbors, and

lastly through the two remaining ones, the flow being regulated with the gates that there may be an even distribution. The charge is now melted down and stirred at intervals in order to break up lumps. With a furnace that has been tapped dry, the bottom has to be rabbled in order to bring adhering melted parts to the surface. When melted and thoroughly liquefied the slag is skimmed into a settling box or a Devereux-Livingstone settling pot,[1] that particles of matte carried out by the slag may be collected and saved. With zinckose ore it is important to give a good fire before tapping, that there may be a good separation of the mushy, zincky matte (which, being light, floats on the surface of the heavy matte) and the slag. The overflow-slag is collected either in waste-slag pots of from 5 to 6 tons capacity, hauled to the dump electrically and poured, or it is granulated and carried off by a stream of water. Granulating slag from the reverberatory matting furnaces was first introduced in 1888 at the Anaconda Lower Works. In order to reduce the copper contents of this slag, fine pyrites has been sprinkled into it before the final firing up, with the hope that slagged copper may be sulphurized and carried into the matte. The matte is removed from the furnace wholly or only in part, depending on whether it is to be collected and shipped or transferred to the converters. When the furnace is to be tapped dry, which occurs only after several charges (with high concentrations as many as twelve charges) have been treated, and the hearth holds from 18 to 20 inches of matte, this is run into sand moulds or cast-iron moulds of similar form, or it is first collected in a steel ladle, and then poured into the form of flat cakes. With a converter plant only part of the matte is removed after every charge, the aim being to keep the level as nearly constant as possible. With furnaces that are tapped dry, the sides are patched or fettled after every tap. With converter plants, fettling of the matting reverberatories is resorted to only once every four or five weeks. As fettling material, siliceous gold ore has, in some instances, replaced the usual sand. A furnace runs about ninety days before it needs sufficient repairs to require shutting down. The subjoined partial analysis of flue dust collected in the gas checkers of a furnace gave:

Insoluble, 91.1 per cent.; SiO_2, 62.2; Fe_2O_3, 8.2; Al_2O_3, 25.7; CaO, 1.8; MgO, none; S, 0.30; CuO, 2.3.

Evidently considerable coal ash was carried over by the gas.

[1] Hofman, *Lead*, 1899, p. 267.

The material formed in the air checkers resembles slag very much in analysis, except that it is higher in copper (*i. e.*, 5 to 9 per cent.), silica, and alumina, and a trifle lower in iron.

VII. Converting Copper Matte.

The converting of copper matte has undergone many changes in the form of apparatus and the mode of working since 1884, when the first converter was put into operation.

The original Parrot converter,[1] swinging in a vertical plane, was $8\frac{1}{2}$ feet high and 5 feet in diameter, outside dimensions. The matte was melted down in a cupola and tapped into the converter through a launder. In 1886 the original method of working in separate stages was changed, and 50-per cent. matte was brought forward to coarse copper in one operation. As the initial charge was 2,500 pounds of matte, increasing to a maximum of 9,000 pounds, the siliceous lining being eaten and worn away, the amount of coarse copper produced in a blow was relatively small. The largest upright converter in Montana[2] is 14 feet $2\frac{1}{4}$ inches in height and 7 feet in diameter, outside dimensions. It works with an average charge of 5 tons and a final charge of 11 tons of 50-per cent. copper matte, receiving it as direct matte from the forehearth of the blast furnace or from the reverberatory furnace. Working direct matte was planned in 1890–91 by the late C. O. Parsons, and carried out by F. Klepetko in 1892; matte was transferred from reverberatory and blast furnaces by means of ladle and electric crane to the converter. At two plants a medium-sized converter was lifted by means of an overhead traveling crane from its trunnion supports and brought to the blast or reverberatory matting furnace to receive its liquid charge; this method has become obsolete, but it has its advantages.

At present the Parsons-Klepetko method is generally employed. A converter charge is tapped from the blast-furnace forehearth, or the reverberatory matting furnace, into a steel ladle managed by an electric traveling crane and poured into the converter. Ladles vary in size; a common form has a diameter of 5 feet and a height of 3 feet 10 inches. The lining, ordinary loam, is plastered on by hand,

[1] Peters, *op. cit.*, p. 529. Stickney, *The Mineral Industry*, I, p. 154.

[2] The largest upright converters are those of Aguas Calientes, Mexico: height, 16 feet; diameter, 8 feet.

dried by an air current and then by a fire (wood, coke); converter slag, to the thickness of 3 inches, is then poured in. Matte-ladles are used also as slag-ladles. A lining is good for $9\frac{1}{2}$ tons of copper.

When the 50-per cent. matte has been blown to white metal, the slag is skimmed and the converter very often recharged with 50-per cent. matte and blown through the slagging stage; but more commonly the original charge of matte is blown to coarse copper after skimming without addition of fresh matte. Doubling charges is a common procedure on matte running less than 50 per cent. copper. After skimming the slag the white metal is brought forward to coarse copper. By these double charges considerable amount of copper is produced in one blow, to be poured into the form of shipping ingots, from 200 to 250 pounds, or anodes, or into a refining furnace, to be refined before casting into anodes.

The upright converter has been replaced in the new plants by the David-Manhès or barrel or trough converter, swinging in a horizontal plane. Here we find two sizes: the smaller, in more general use, is 7 feet in diameter and 10 feet 6 inches long; it receives an initial double charge of 5 tons and a final double charge of 12 tons 50-per cent. matte; the larger one is 8 feet in diameter and 12 feet 5 inches long; the initial double charge is 10 tons, and the final double charge is 20 tons. The main reason for replacing the upright by the horizontal converter is the low blast pressure required by the latter type, 10 versus 15 pounds, although this advantage suffers greatly by the difficulty of making the lining firm, a thing relatively easily accomplished in the vertical converter. Converting matte in a bottom-blown upright vessel has been tried. This was 13 feet high and 7 feet in diameter, had sixteen $\frac{3}{4}$-inch tuyères placed in a manner similar to that which obtains in making steel by the Bessemer process. The experiments were successful so far as the process proper was concerned, *i.e.*, 50-per cent. matte was satisfactorily brought forward to coarse copper, which remained sufficiently fluid to be poured satisfactorily. They appear to show that the failure of Manhès to use a bottom-blast converter[1] in his first experiments was probably due to his operating with too small a vessel from which matte and slag were blown out, and with too little matte, which furnished only a small amount of copper quickly chilled by the blast. The Montana experiments have not been followed up for the present, as the life of the bottom was too short, parts of it floating up

[1] Grüner, *Bulletin de l'Industrie Minérale de Ste. Étienne*, 1885, XIV, p. 607.

during a blow. The experience gained so far tends to show that the bottom-blown converter works more quickly than the side-blown, that the wear of the lining is more even, and that the critical points are less easily discovered and have to be watched with great care. When the question of lining the bottom will have been settled satisfactorily, it is believed that blowing from the side will be given up, at least with a large converter having an initial charge of 5 tons 50-per cent. matte. A gyratory motion of the charge, obtained by placing the bottom tuyères inclined, as in the David *Selecteur*,[1] may lengthen the life of a converter lining.

In all plants the converters are placed in a single row, forming a straight line. Back of them is the main flue (vacuum 0.1 inch water), with projecting hoods, into which the converters discharge their gases, vapors, and finely divided particles of charge (called flue-dust). The main flue ends in a dust chamber (temperature 370° C.) connected with a stack. At some works the matte is poured into a converter at the front from a suspended ladle; at others it arrives at the back (above the main flue) in a ladle, and is poured into a launder, which delivers it at the front. A stall is served by from two to two and one-half converters and from one and one-half to two ladles. The lining of converters, both of body and of caps, is still causing trouble, as in the most favorable case the body has to be removed after 28 tons of copper have been treated; the cap has a longer life. The material is, of course, siliceous. A greenish granular sandstone (SiO_2, 64.4; FeO, 7.6; Al_2O_3, 16.5; CaO, 1.1; MgO, 1.8; Ignition loss, 4.7), which readily crumbles when exposed to the air, is used without any admixture of a bond. A crushed quartzite pugged with 5 per cent. clay gives a satisfactory mixture (SiO_2, 88.6; Fe_2O_3, 3.1; Al_2O_3, 4.0; CaO, 1.6); lining-sand has been mixed with slimes from the ore-dressing works (insoluble, 75.3; SiO_2, 60.0; Fe, 2.2; Al_2O_3, 19.9; S, 6.8; As and Sb, 0.75; Cu, 6.05) and with second-class ore (insoluble, 68.9; SiO_2, 57.0; Fe, 9.6; Al_2O_3, 10.4; S, 15.95; Cu, 5.95; Ag, 2 ounces per ton), giving the following material:

Insoluble, 82.2; SiO_2, 63.0; Fe, 5.9; Al_2O_3, 17.3; CaO, 1.5; MgO, 1.3; S, 2.1; Cu, 1.0; H_2O, 11.0; ignition loss, 4.1.

Another mixture for the body of the converters consists of quartzite (SiO_2, 90 to 91; Al_2O_3, 2.0; FeO, 3.0; Ag, 10 to 20 ounces per ton)

[1] P. L. Burthe, *Annales des Mines*, 1898, XIII, p. 621. *Engineering and Mining Journal*, Oct. 22, 1898.

and slimes (SiO_2, 60; Fe, 4 to 5; Al_2O_3, 15; S, 9; Cu, 5 to 7) to form a lining (SiO_2, 85; Fe, 3.3; Al_2O_3, 4; S, 3; Cu, 4; Ag, 12 ounces per ton).

Table XI gives analyses of all the materials used to make the converter-lining.

TABLE XI.—ANALYSES OF CONVERTER LININGS.

	SiO_2.	Fe.	Al_2O_3.	CaO.	MgO.	Loss on Ignition.	S.	Cu.	Oz. Ag. per Ton.	As and Sb.	H_2O.
Greenish, granular sandstone, Great Falls	64.4	5.9	16.5	1.1	1.8	4.7	. .	. .	. .	. .	. .
Crushed quartzite, with 5 per cent. clay	88.6	2.2	4.0	1.6	. .	. .	. .	. .	. .	. .	. .
Sandstone, slimes and second-class ore	68.0	5.9	17.3	1.5	1.3	4.1	2.1	1.0	. .	. .	11.0
Quartzite and slimes	85.0	2.5	4.0	. .	. .	. .	3.0	4.0	12.0	. .	. .
Sandstone	64.4	5.9	16.5	1.1	1.8	4.7	. .	. .	. .	. .	. .
Slimes	60.0	2.2	19.9	. .	. .	. .	6.8	6.05	. .	0.75	. .
Second-class ore	57.0	9.6	10.4	. .	. .	. .	15.95	5.95	2.0	. .	. .
Quartzite	90–91	2.7	3–2	. .	. .	. .	. .	. .	10–20	. .	. .
Slimes	60.0	4–5	15	. .	. .	. .	9.0	5.7	. .	. .	. .

In some instances siliceous gold ores have been worked in as a lining material. The material for the cap is generally made more plastic than that of the body. The lining usually consists of body-lining material and 5 to 10 per cent. of clay, and is mixed with more water than the body material. If the lining of the body were eaten away solely by the scorifying action of the iron, its life would be much longer than it is. The chemical action in some instances plays even a subordinate part to the mechanical wear by the swash of the liquid charge, which causes part of the lining to break off. This is especially observable in the barrel converter. The chemical wear takes place mainly near the tuyères, the mechanical wear at the opposite side near the top of the body. In an upright converter 14 feet 2 inches high and 7 feet in diameter, the bottom lining will be 22 inches thick, the side lining at the tuyères will be 30 inches thick, and on the opposite only 18 inches, while at the top of the body the lining on the tuyère side will be $17\frac{3}{4}$ and opposite $27\frac{3}{4}$ inches thick.

In a horizontal converter 10 feet 6 inches long and 7 feet in diameter, the bottom will be 18 inches thick, consisting of a 4-inch segmental layer of mixture tamped onto the steel shell, followed by a slightly curved $4\frac{1}{2}$-inch course of brick and by a 10-inch layer of mixture. The sides are lined with a course of $4\frac{1}{2}$-inch fire brick, special brick $6\frac{1}{2}$ by $6\frac{1}{2}$ by 4 inches being used at the tuyère level. A cross section through the tuyère level will show the sand lining to be 30 inches at the tuyères and 16 inches opposite; at the top of the body the corresponding dimensions will be 20 and 20 inches. The longitudinal section will show the side lining to be 16 inches at top of the bottom lining and 34 inches at the top of the body. The ends are not lined with brick. Sometimes the lining is still rammed in by hand; an air-drill adapted for the purpose or the flask-tamper of the foundryman is more common.

The ramming is done by contract, a premium being paid if the converter makes more than the standard amount of copper on a lining, and deductions made if it falls below it. If the lining is to be patched, the vessel is first emptied and then cooled with water from the outside; then lining material is rammed in or a few scoopfuls of infusible odds and ends are thrown in, tamped down, and slag thrown over the patch. Occasionally matte is run into the empty converter and allowed to solidify. Experiments in lengthening the life of the converter-lining by pouring siliceous blast-furnace slag into the converters, with the hope that the excess of silica over that of the normal converter slag would combine with the oxidized iron from the matte, have been only partially successful.

The difficulty and expense of handling converter slag have been overcome in one plant by the use of slag casting-machine.

The average time to complete a charge with a 5-ton upright converter is two hours fifty-five minutes; this figure is reduced to two hours twenty minutes, if the time taken up by pouring and waiting is excluded. The blowing of a single charge takes forty-seven minutes; a double charge takes eighty-two minutes. In pouring the slag a rabble is pushed in and out of the stream of slag. The appearance of bright, sizzling specks is a sign that white metal is coming over. A few partial analyses of the products obtained in converting are subjoined:

TABLE XII.— ANALYSES OF CONVERTER PRODUCTS.

	Cu.	SiO_2.	FeO.	Al_2O_3.	CaO.	Ag, Au, Ozs. per Ton.	S.	As and Sb.
Slag	2.0	30.0	55.2	9.5	1.0	. .	. .	. .
Slag	1.6	29.8	57.8	10.0	1.0	0.8	. .	. .
Slag	5–6	31–32	54.0	. .	. .	. .	. .	. .
Dust	37.8	1.5	7.4	1.9	None.	. .	14.3	4.8
Dust	63.4	3.8	12.8	. .	. .	53.8	16.0	. .
Dust	65.0	. .	. .	. .	. .	. . .	. .	. .
Pig copper	99.0	. .	. .	. .	. .	9–40	. .	. .

The labor required per shift for a single converter is made up of one skimmer, one puncher, one helper, and one sampler.

With three large horizontal converters running as steadily as possible, the number is one skimmer, two punchers, two helpers, and two samplers.

In Table XIII some of the data given previously have been summarized, and some additional facts have been added.

TABLE XIII. — MONTANA CONVERTERS.

Converter.	Grade of Matte.	Horizontal Section at Tuyères.	* Lining Material per Converter.	Lining per Ton Copper Resulting.	Copper per Converter.	Tuyères.		Maximum Pressure.
	p. c. Cu.	Sq. ft.	Tons.	Tons.	Tons.	No.	Diam.	Lbs.
Upright vessel, 7 feet x 14 feet 7 inches	51.1	7.07	7.63	.53	14.8	8	$\frac{3}{4}$	18
Medium barrel, 7 feet x 10 feet 6 inches	51.7	6.66	8.40	.32	26.2	14	$\frac{3}{4}$	12
Large barrel, 8 feet x 12 feet 6 inches	45.0	17.79	16.60	.80	20.0	18	$1\frac{1}{4}$	15

* These data do not show the amount of lining material required to line a *new* converter, but only the average weight put in after a lining is worn down to the point where further charges would endanger the iron shell.

It will be seen that the medium barrel uses much less lining per ton of resulting copper than the upright vessel, although the grade of the matte differs only slightly. This may be explained by the more siliceous character of the lining used, as, except for the mechanical effect of making the material plastic, alumina would be of no service in scorifying; furthermore, the lining of the upright vessel runs higher in iron.

The lining of the large barrel is of about the same quality as that used with the medium barrel; but as the matte of the former is of a lower grade, the quantity of lining used per ton of resulting copper is naturally higher.

Converter Lining.	SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.
Medium barrel	91.0	3.0	3.8	1.6	. .
Upright vessel	64.4	8.4	16.5	1.1	1.8

In the upright vessel the amount of free air used per ton of copper converted is about 200,000 cubic feet, not allowing for "leakage" in the blowing engines.

Yield of Metal. — The general yield of metal in roasting, smelting, and converting, in treating an ore assaying 10 to 12 per cent. copper and about 4 ounces silver per ton, is copper 92 + and silver 95 + per cent.

VIII. Electrolytic Refining of Copper.

The work of the two electrolytic refining plants in the Butte district, at Great Falls and Anaconda, is of especial interest, as they work under different conditions of power, while they treat similar anode copper by the multiple process. The works at Great Falls, driven by water power, have 312 tanks, 9 feet 9 inches long by 2 feet 4 inches wide by 3 feet 9 inches deep, in three sets of 104 tanks, each set having a separate solution; a tank is charged with twenty anodes and twenty cathodes; the current is of forty amperes per square foot of cathode area; two Westinghouse direct-current machines generate 9,000 amperes at 200 volts. The works of Anaconda,[1] driven by steam power, have 1,400 tanks 8 feet 2 inches long by 4 feet 5 inches wide by 4 feet 6 inches deep in sets of 200 each. A tank is charged with thirty-eight double anodes and eighty cathodes; the current is of ten amperes per square foot of cathode area. There are seven dynamos, each generating 4,000 amperes at sixty volts for 200 vats.

The anodes of the Butte district assay Cu, 98 to 99 per cent.; Ag, 40 to 120 ounces per ton; Au, 0.1 to 1.5 ounces per ton. They are cast either direct from the converter, or the converter copper is first refined in a reverberatory furnace.[2]

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[1] *Engineering and Mining Journal*, Sept. 19, 1896.

[2] Refining converter copper before casting into anodes has been given up at Great Falls, in spite of the advantages mentioned later on in the text as regards corroding, because the gain did not warrant the expense. At Anaconda, where power is generated by steam, it is of considerable advantage to have refined anodes.

The converter charge is blown to the point at which the copper still retains considerable sulphur dioxide in solution. In pouring anodes from the converter, the copper strikes a launder swung in position, which delivers the copper into open flat moulds resting on a car moved slowly on rails laid between the posts of a stand. The strong evolution of sulphurous gas upon cooling makes the anodes very uneven. The moulds are of copper, but have cast-iron centres that take up the impinging force of the stream of metal. If the copper is first to be refined, the metal from several converters is emptied into ladles which discharge their contents into the stationary refining furnaces. Here the rabbling of the copper, in order to cause the oxidation necessary to produce set copper, has been replaced by forcing air into the copper by 1-inch wrought-iron pipes inserted through the side- and end-doors of the refining furnace. The two hours required for rabbling have been reduced to one and one-quarter hours by blowing; 6 feet of pipe are used up with a 40-ton charge. Oxidation is continued until a small ladle-sample when broken shows the characteristic single bubble in the depressed centre. Care is taken to bring the copper only to this point, when the copper is saturated with cuprous oxide, as otherwise the surface will quickly become oxidized and covered with melted oxide. The set copper is then poled to tough-pitch copper, fifteen poles (3 inches at end, 7 inches at butt, and 15 to 18 feet long) being required for 50 tons of copper. From the reverberatory furnace the anodes are cast by means of an improved form of Walker casting machine.[1]

A tilting reverberatory furnace constructed along the general lines of the Brückner cylinder was used at the old Anaconda works, but given up after a short trial.

Converter anodes are less evenly corroded, give more scrap, and furnish a mud of lower grade than do anodes from the refining furnace. Coarse copper, *e.g.*, with Cu, 99.27 per cent.; As and Sb, 0.07 per cent.; Ag, 61.14 and Au, 0.22 ounces per ton, cast from the converters into anodes gave 8 per cent. scrap, and the anode mud, after having been passed through a 40-mesh sieve, washed and dried, contained Cu, 41 per cent.; Ag, 7,000 and Au, 18 ounces per ton. Similar copper refined in the reverberatory furnace and then cast into anodes gave in corroding only 5.5 per cent. scrap, while the 40-mesh anode mud assayed Cu, 18 per cent.; Ag, 15,000, and Au, 38 ounces per ton.

[1] *The Mineral Industry*, VII, p. 252.

The Great Falls anodes are 24 inches wide by 35 inches long by 3 inches thick at the top and $2\frac{1}{2}$ inches thick at the bottom; they are beveled at the bottom; the two lugs on top are $4\frac{1}{2}$ inches wide by $2\frac{1}{2}$ inches long by 2 inches thick. The anodes are suspended from cast-copper crossbars ($1\frac{1}{2}$ inches by $1\frac{1}{4}$ inches) by means of the Morrow clip,[1] a loop of sheet copper $2\frac{1}{8}$ inches wide (recently replaced by a rod $\frac{1}{4}$ inch in diameter) by $3\frac{1}{2}$ inches high, the ends of which are allowed to project into the anode moulds before they are filled with liquid copper. A converter anode weighs 500 pounds, and is sufficiently corroded in about eighteen days to be withdrawn and regarded as scrap, a new anode being put in its place. The Anaconda anodes are 24 to $24\frac{1}{2}$ inches wide, $32\frac{7}{8}$ inches long, and $1\frac{1}{4}$ inches thick at the top, and 1 inch at the bottom. They have two top lugs 6 inches wide with holes, and are suspended in pairs from iron copper-covered crossbars ($\frac{1}{2}$ by $1\frac{3}{4}$ inches), nineteen to a tank, by means of copper hooks $\frac{3}{8}$ inch thick. An anode weighs 230 pounds and is corroded in thirty-seven days.

The cathodes are made in the usual way in tanks set apart for the purpose. They are slightly longer and wider than the anodes. At Great Falls they are 26 inches wide by $36\frac{1}{2}$ inches long and weigh $2\frac{1}{2}$ pounds; at Anaconda they are 11 inches wide by 33 inches long and weigh $\frac{3}{4}$ to 1 pound. At Great Falls the cathodes are suspended by the Morrow clip, which is fastened to the starting sheet by a machine,[2] which punches a hole through the loop and sheet, bends over the lugs, and clamps them fast. At Anaconda the upper rim of the starting sheet is bent and clamped over the ends of a piece of sheet copper $4\frac{1}{2}$ inches wide by 11 inches long; four cathodes go to a crossbar; the electrode-distance ranges from $1\frac{1}{2}$ inches to 2 inches.

The tanks are made of 3-inch plank, and are lined with 8-pound lead; the bottoms have a board cover to protect the lead lining from pieces of anode copper that may become detached. At Great Falls the vats are arranged in pairs with three conductor bars, the central bar serving as cathode-bar for one tank, and as anode-bar for the other.[3] At Anaconda, with the Thofern disposition, the tanks are arranged in single rows.[4]

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[1] *United States Patents*, No. 621,121, March 14, 1899; No. 631,471, Aug. 22, 1899.

[2] *United States Patent*, No. 600,498, March 8, 1898.

[3] Illustration in *The Mineral Industry*, VII, p. 186.

[4] *Berg- und Hüttenmännische Zeitung*. 1893, p. 54.

The electrolyte contains with the heavier current 170 grammes concentrated sulphuric acid and 42 grammes copper per litre; with the lighter current, 150 grammes acid and 40 grammes copper. The resistance appears to begin to increase when the copper rises above 42 grammes. The temperature of the electrolyte at the head tank is 64° C. and 50° C., and the circulation six and three gallons per minute. Solutions are admitted and drawn off either at the ends or the sides, precautions being taken by means of perforated lead baffle-plates to have an even distribution, and thus avoid stirring up any mud. The different forms of plunger pumps, which were formerly used to raise the electrolyte, have given way to Pohle's air-lift pumps working under a pressure of 25 pounds. These have proved very satisfactory, especially since the delivery pipe has been cut in two near the discharge and the ends joined by a rubber hose, thus breaking any electric connection. The electrolyte becomes enriched in copper, and takes up iron, arsenic, and antimony. A foul solution contained, *e.g.*, per litre:

Cu, 51.8 grammes; Fe, 13.2 grammes; As, 14.02 grammes; Sb, 0.62 grammes; H_2SO_4, 48 grammes.

The low percentage of antimony is due to the practice of adding daily enough concentrated crude hydrochloric acid to the head tank to maintain .04 grammes chlorine per litre in solution. This addition precipitates antimony, it is believed, as oxychloride. When there is deficiency of hydrochloric acid, a sample-plate becomes streaked, tarnished, black, and at the same time brittle. The excess of copper over the normal is removed by shunting off part of the electrolyte and making it pass through tanks with lead anodes. By retarding the flow of this current through a second set of tanks, arsenic will be deposited with the rest of the copper. The slime deposited in such a purifying vat showed Cu, 57.1 per cent.; H_2SO_4, 11.8 per cent.; Ag, 0.3 per cent.; As, 7.2 per cent.; Sb, 1.8 per cent.; H_2O, 18.4 per cent.; difference: traces of $PbSO_4$ and traces of Fe.

While the difference in potential between electrodes with soluble anodes is 0.6 (Great Falls) and 0.3 (Anaconda) volt, with insoluble anodes it rises to 2.5 and 2.0 volts. When iron is to be removed the solution, freed from copper and arsenic, is concentrated by heating to one-third of its volume and then cooled, when most of the iron will crystallize out in the form of ferrous sulphate. At Great Falls the cathodes are renewed every second day. They weigh 55 pounds and

contain Cu, 99.95 per cent.; As, 0.0012 per cent.; Sb, 0.0033 per cent.; Ag, 1 ounce per ton. Although this method of working uses up a large number of starting-sheets, it is found to be advantageous, as with the large current of forty amperes there is a loss in efficiency on account of short circuiting if the cathodes are allowed to grow heavier. Thus with two-day cathodes there is an ampere efficiency of 91 per cent., while with four-day cathodes this falls off to 85 per cent. The cathodes, taken out four at a time by means of an overhead traveling pulley, are transferred to lead-lined cars and replaced by starting-sheets. The twenty cathodes in a car are then raised together by means of an electric crane dipped into water, drained, dipped into milk of lime, and allowed to dry. The coat of lime protects the plates in melting down from the sulphurous gases in the products of combustion of the refining furnace.

At Anaconda cathodes are removed only when the anodes are completely corroded. After two days' depositing they are, however, taken out and straightened. A tank receives at once all its anodes; in the same way all the cathodes are taken out by one operation.

The anode mud made at Great Falls is removed by a steam-injector pump and rubber hose from the electrolyzing vat into a settling tank covered with a forty-mesh screen; it is then drawn off into an acid egg, forced through a filter press, steam dried (when it still retains 2 per cent. water), broken up, sampled, sacked and sold.

At Anaconda the anode mud is discharged through an opening in the bottom of the electrolyzing vat, after the solution has been drawn off from the side, into a V-shaped trough leading into a tank; from this it is drawn into an acid egg, and forced into a tank in the refining department, drawn onto filter cloths, washed, dried, sampled, sacked and sold. Until recently the mud was treated at the works. It was melted down in a reverberatory furnace, refined by the addition of nitre, cast into small ingots, and parted with sulphuric acid, the silver being precipitated by means of copper.

The anode scrap at Great Falls is remelted in the converter, while at Anaconda it goes back into the anode furnace.

The leading facts of the two refining plants are brought together in Table XIV.

Refining of Cathodes. — The reverberatory furnaces used for refining converter and cathode metal have retained the pear-shaped form of the original Welsh furnaces. They have charging doors on both sides,

and the usual working and ladling doors at one end; and there are air flues in the bridge leading onto the hearth.

The following are the leading details of a standard furnace: length of hearth, 22 feet 6 inches; width at bridge, 7 feet 1.5 inches; at middle, 14 feet 8 inches; at flue, 1 foot 8 inches; hearth area, 225 square feet; thickness of hearth at bridge, 2 feet 7 inches; at flue, 2 feet;

TABLE XIV.—DETAILS OF ELECTROLYTIC REFINERIES.

	GREAT FALLS.	ANACONDA.
Number of tanks	312	1,400
Length " "	9 ft. 9 in.	8 ft. 2 in. (inside meas.)
Width " "	2 ft. 4 in.	4 ft. 5 in. (inside meas.)
Depth " "	3 ft. 9 in.	4 ft. 6 in. (inside meas.)
Number of tanks per set, *i. e.*, number of tanks using same solution	204	200
Number of anodes per tank	20	38
" " cathodes per tank	20	80
" " amperes per square foot of cathode area	40	10
Power:		
Number of generators	2	7
" " circuits	1	7
Amperes generated per circuit	9,000	4,000
Volts per circuit	200	60
Character of material worked	Converter anodes	Casting furnace anodes
Kind of moulds used	Copper	Iron
Casting machines, pattern	Walker	Anaconda
Converter anodes, per cent. Cu	99.1	. . .
" " " " As and Sb	0.07	. . .
" " oz. Ag	56.00	. . .
" " oz. Au.	0.20	. . .
" " per cent. scrap	8.00	. . .
" " mud, per cent. Cu	41.0	. . .
" " " oz. Ag	7,000.0	. . .
" " " oz. Au	18.0	. . .
Refined anodes, per cent. Cu	99.27	99.25
" " " " As and Sb	0.07	0.10
" " oz. Ag	61.14	90.00
" " oz. Au	0.22	0.50
" " per cent. scrap	5.5	7.00
" " mud, per cent. Cu	18.00	10.00
" " " oz. Ag	15,000.0	18,000.0
" " " oz. Au	38.00	100.00
Size of anodes:		
Length	35 in.	32¼ in.
Width	24 in.	24½ in.
Thickness	3 in., 2½ in.	1¼ in., 1 in.
Weight in pounds, converter	500	. . .
" " " refined	632	230
Number of days corroding, refined anode	. . .	37
" " " converter anode	18	. . .
Size of cathodes:		
Length	36½ in.	33 in.
Width	26 in.	11 in.
Weight of starting sheets, lbs.	2½	¾, 1
Weight of cathodes, lbs.	55	100
Number of cathodes on one bar	1	4
Electrolyte:		
Sulphuric acid per litre, grms.	170	150
Copper per litre, grms.	42	40
Temperature at head tank, C.	64	50
Circulation per minute, gals.	6	3
Difference in potential:		
Soluble anodes, per tank	0.6	0.3
Insoluble " " "	2.5	2.0
Composition of cathodes, per cent. Cu	99.95	99.96
" " " " " As	0.0012	0.0009
" " " " " Sb	0.0033	0.0023
" " " oz. Ag	1.0	0.25

depth of metal, 12 to 13 inches; length of grate, 8 feet 6 inches; width, 7 feet 1.5 inches; depth of grate below top of bridge, 2 feet 6 inches; ratio of grate to hearth area, 1 : 3.7; height of roof above bridge, 1 foot 10 inches; above hearth at bridge, 2 feet 3 inches; at flue, 1 foot 10 inches; rise of arch, 1 inch per foot; size of flue at vulcatory, 3 feet 9 inches by 19 inches; of flue leading to chimney, 24 by 19 inches; size of chimney, 32 by 32 inches; height, 80 feet. Charge: liquid metal, 125,000 pounds; cathodes, 75,000 pounds. Analysis of bituminous coal: ash, 18.8; fixed carbon, 54.6; proportion of charge to coal by weight, 3 : 1; tons of charge to number of poles, 4 : 1; tons of charge to bushels of charcoal, 1 : 1.

The method of working differs little from that in common use, excepting that flapping or rabbling is replaced by blowing with compressed air (see *ante*); the metal bath in poling is covered with charcoal only toward the end of the operation, a few old poles, however, floating on the metal; of the two poles inserted through the working door, one is depressed near the door, the other toward the middle of the furnace; ingots, cakes, and wire bars are cast by means of suspended ladles 14 inches and 19 inches in diameter. All moulds are of copper. Cake and wire-bar moulds are painted with a mixture of lamp black and benzine; they are warmed at first by pouring in some copper. Ingot moulds are smoked before the first round by means of burning rosin held in a ladle. The tests applied to the copper are those of the Bell Telephone Company for Number 12 wire: conductivity, 96 to 97 per cent.; tensile strength, 65,600 pounds; torsion, forty twists in 6 inches between the clamps with 1 per cent. elongation. Three test bars are made from each charge, one bar being made when dipping begins, one when the charge is half out, and the third at the conclusion of the ladling. The test bars are 8 inches long, and have the full cross section of a regular wire bar. From each of these bars a section 6 inches long by 1 inch square is sawed; this section is rolled into a rod and afterward drawn cold to a Number 12 wire, Brown and Sharpe gauge, on which all tests are made. Conductivity tests are made with the Willyoung conductivity bridge.[1]

In conclusion, the writer wishes to express his thanks to the management and officers of the different companies for the courtesies shown him, and for the privilege of presenting to the Institute that part of his notes which is of general metallurgical interest.

[1] M. E. Leeds & Co., Philadelphia, Pa.

APPENDIX.

TABLE XV.—THE EFFICIENCY OF SOME ROCKY MOUNTAIN COALS.*

	Summary of Chemical Tests.							Summary of Efficiencies.					
	Volatile matter.	Fixed carbon.	Total.	H_2O.	Ash.	Calories.	B. T. U.	Price per ton.	Evaporation from and at 212° F.	Cost to evaporate 1,000 lbs. water.	Relative value.	B. T. U. of coal.	Boiler efficiency.
Trail Creek (Mt. House) nut	25.92	48.85	74.77	9.04	16.19	7,534	13,561	$2.85	4.65	$0.306	$2.68	10,141	44.27
Trail Creek (Mt. House) lump	25.34	52.62	77.96	8.75	13.29	7,734	13,921	4.15	5.70	0.360	3.28	10,863	50.00
Red Lodge lump	26.24	52.39	78.63	9.23	12.14	7,245	13,041	4.50	6.50	0.345	3.74	10,255	61.00
Bridger lump	26.55	54.00	80.55	7.67	11.78	7,465	13,437	4.50	6.10	0.371	3.51	10,824	54.30
Sheridan, Wyoming, lump	26.78	46.40	73.18	21.20	5.62	7,006	12,611	5.50	5.01	0.547	2.88	9,229	52.40
Red Lodge washed nut	26.15	53.52	79.67	9.05	11.28	7,205	12,970	3.75	5.40	0.346	3.11	10,332	50.60
Chestnut washed mine run	23.10	50.18	73.28	8.64	18.08	8,407	15,133	3.05	5.30	0.288	3.05	11,090	46.50
Gebo lump	21.46	47.40	68.86	6.42	24.72	8,241	14,834	4.00	5.75	0.346	3.31	10,215	54.40
Bridger nut	30.00	50.64	80.64	3.95	15.41	7,195	12,952	3.75	4.86	0.386	2.80	10,444	44.80
Trail Creek (Kountz's) lump	26.24	47.65	73.89	12.41	13.70	7,167	12,901	4.50	5.44	0.413	3.13	9,533	55.00
Belt washed nut †	22.65	55.00	77.65	4.23	18.12	7,445	13,402	4.50	5.60	0.400	3.22	10,406	52.00
Galt (Canada) lump †	24.28	57.45	81.73	8.00	10.27	7,421	13,359	6.50	6.05	0.535	3.49	10,919	53.10
Rock Springs (Wyoming) lump †	27.90	61.31	89.21	5.64	5.15	7,686	13,836	6.75	7.55	0.447	4.35	12,343	59.00
Mountain Side mine run	26.84	49.91	76.75	2.71	20.54	7,918	14,252	3.40	5.78	0.294	3.32	10,938	51.00

* Taken from a paper read before Montana Society of Engineers by Prof. W. H. Williams, State Agricultural College, Bozeman, Montana, through *The Western Mining World*, Nov. 15, 1902.

† Price in Butte. Relative value compared to chestnut-washed mine run.

RESULTS OF TESTS MADE IN ENGINEERING LABORATORIES.

XIV.

STEAM.

TEST OF THE WESTINGHOUSE UNIT AT LINCOLN WHARF POWER STATION OF BOSTON ELEVATED RAILWAY COMPANY, MAY 7, 8, 9, 1903.

THROUGH the courtesy of the directors of the Boston Elevated Railway Company and Mr. C. F. Baker, Master Mechanic, permission to test the Lincoln Wharf plant was given the senior class of engineering students of the Massachusetts Institute of Technology.

The test was carried on by 108 students under the direction of the regular instructing staff of the engineering laboratories.

The test was divided into four watches of ten hours each, twenty-seven men under the direction of two instructors working on each watch.

Only one of the three units in the station was tested. This unit was separated entirely from the others. In every case where there was a possibility of leakage pipes were cut and blanked. This necessitated many changes.

Steam was furnished to the engine from four Babcock and Wilcox boilers, three of which were provided with superheating pipes in the first gas passage. These four boilers supplied nothing but the engine. The auxiliaries, including two stoker engines and the air pump, were supplied with steam drawn from another battery. The steam supplied to these auxiliaries was measured by means of orifices through which the steam flowed on the way to each.

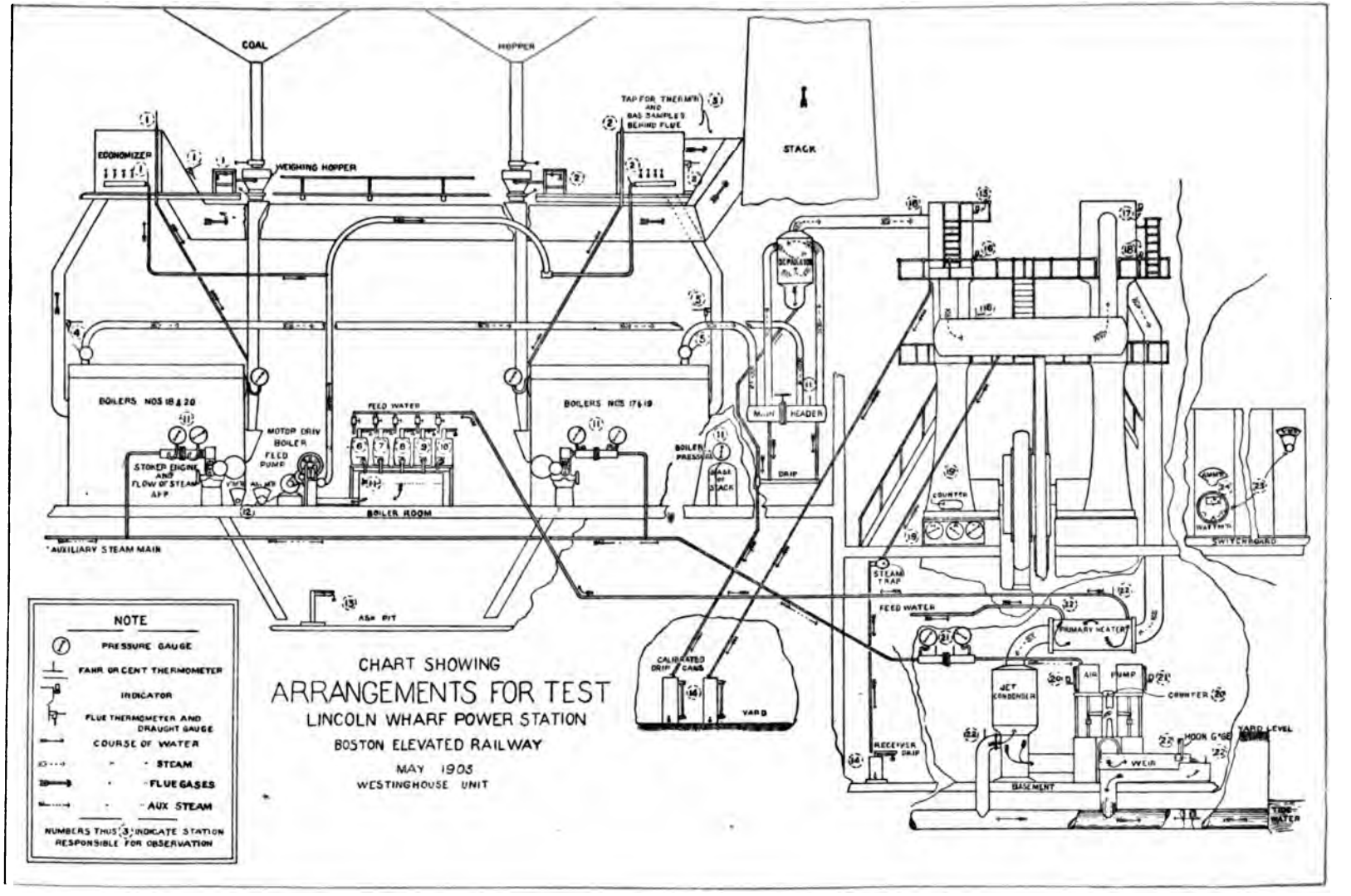

CHART SHOWING

ARRANGEMENTS FOR TEST

LINCOLN WHARF POWER STATION

BOSTON ELEVATED RAILWAY

MAY 1903

WESTINGHOUSE UNIT

In this way it was possible to find the steam supplied to the engine with greater accuracy than if the auxiliaries had been fed from the same boilers.

Previous to starting the test the engine had been running for some hours at the load maintained constant during the test.

The electrical output was kept as nearly constant as possible; during the day this was accomplished by making up with another machine the extra amount demanded from this station; during the night, when the demand was less than the load on the engine, a water rheostat was connected across the line.

As students were stationed at five different levels in both the boiler room and the engine room, the accompanying chart was printed for the students to enable them to locate all points where observations were to be made.

This chart together with the list of stations shows clearly what observations were taken and the arrangement of piping as changed for the test.

LIST OF STATIONS, DUTIES, ETC. LINCOLN WHARF POWER STATION, ATLANTIC AVENUE, BOSTON.

No. of Station.	Duties.	Location.
1	Weigh coal for boiler No. 18 Weigh coal for boiler No. 20 Take temperature in flue, boilers No. 18 and No. 20 Take draft readings in flue, boilers No. 18 and No. 20 Take temperature of feed water entering and leaving ecopomizer	Economizer level, boilers No. 18 and No. 20
2	For boilers No. 17 and No. 19 Same as Station 1	Economizer level, boilers No. 17 and No. 19
3	Take temperature in main flue Take samples and analyze gases from main flue	Economizer level, boilers No. 17 and No. 19
4	Take temperature of steam from boiler No. 18 Take temperature of steam from boiler No. 20 Take draft in uptake, boiler No. 18 Take draft in uptake, boiler No. 20 Take temperature in uptake, boiler No. 18 Take temperature in uptake, boiler No. 20	Top of boilers No. 18 and No. 20
5	Same as Station 4 for boilers No. 17 and 19	Top of boilers No. 17 and No. 19
6	Weigh feed water	Boiler room. Water weighing platform
7	Weigh feed water	
8	Weigh feed water	
9	Weigh feed water	
10	Weigh feed water	
11	Read boiler gauge at header Take temperature of steam at header Take pressures at flow of steam apparatus for stoker engine, boilers No. 17 and No. 19 Take pressures at flow of steam apparatus for stoker engine, boilers No. 18 and No. 20 Take temperature of feed water in tank	Boiler room floor
12	Take ammeter and voltmeter readings for feed-pump motor	Boiler room floor
13	Weigh ashes, boilers No. 18 and No. 20 Weigh ashes, boilers No. 17 and No. 19	Ash pit floor
14	Take drip-can readings for separator Take drip-can readings for throttle and valve chest Weigh drip barrel from receiver drip trap	Yard near boiler house
15	Take indicator cards: high pressure cylinder, head end Mark cards "H. H.," also with date and time	Engine platform
16	Take indicator cards: high pressure cylinder, crank end Mark cards "H. C.," also with date and time Take temperature of steam supply Take temperature of steam in receiver	Engine platform
17	Take indicator cards: low pressure cylinder, head end Mark cards "L. H.," also with date and time	Engine platform
18	Take indicator cards: low pressure cylinder, crank end Mark cards "L. C.," also with date and time Collect all four cards and carry to planimeter table	Engine platform
19	Keep time Ring gong every fifteen minutes. One stroke on the minute Two strokes ten seconds before minute Three strokes thirty seconds before minute Read pressures at gauge board Boiler, receiver, vacuum Read engine counter and assist at planimeter table on air-pump cards	Engine room floor
20	Read counter at air pump. Stroke Take indicator cards: air pump, head end, and pump end. High pressure cylinder Mark cards "A. H.," also with date and time Carry all cards to planimeter table	Engine foundation floor

LIST OF STATIONS, DUTIES, ETC. LINCOLN WHARF POWER STATION, ATLANTIC AVENUE, BOSTON. — *Continued.*

No. of Station.	Duties.	Location.
21	Take indicator cards: air pump, head end and crank end. Low pressure cylinder Mark cards "A. L.," also with date and time Take temperatures and pressures flow of steam apparatus	Engine foundation floor
22	Read hook gauge at weir Take temperature of feed water entering and leaving heater Take temperature of injector water entering and leaving condenser	Engine foundation floor
23 and 24	Read wattmeter and voltmeter, one-half minute intervals	Switch board
25	Planimeter areas. High pressure cylinder cards Draw and measure ordinates, length, per cents., cut-off, release, and compression Tabulate results	Engine room floor
26	Same as Station 25 for low pressure cylinder cards	Engine room floor
27	Planimeter areas: air pump cards Draw end ordinates and measure lengths Tabulate results	Engine room floor

REMARKS.

There was some difficulty in keeping the safety valves on the boilers from blowing. To prevent this, air was admitted to the boilers through the cleaning doors on the side of the setting. This cut down the efficiency of the boilers and also reduced the saving made in the economizers.

Samples of flue gas showed a large percentage of free oxygen and but little carbonic acid.

With three boilers supplying the steam instead of four, the economy of the plant would have been greater.

A considerable quantity of coal dropped through the grates into the ash pit. This coal was weighed back and returned to the coal pocket according to the regular custom at this station.

Twice during the test the engine exhausted outboard owing to the stopping of the air pump. The total time during which the engine was without vacuum was a little less than two hours.

The electrical output of the engine was dropped about 50 per cent. during these periods.

The thermometers used in measuring the temperature of the steam at the top of the boilers gave considerable trouble from the separation of the mercury thread due to vibrations. This may have caused an error of from one to two degrees in the average of some of these readings.

On calculating the tests it was found that the output of electrical horse power differed from the indicated power only by about 112 horse power.

The indicator springs were tested and found to be practically correct. The electrical instruments were calibrated a second time without appreciable change of result. It was finally discovered that there was some lost motion in the indicator rigs. The indicator rig consisted of a long rod which ran up the side of the cylinder, and which received a partial rotation at each stroke. This motion was obtained from the crosshead through a stud which bore against a helical plate fastened to the long rod. A spring served to keep the stud and helix in contact.

To determine the error due to this lost motion two diagrams were taken on the same card, one with the lost motion taken up and one with the indicator rig as it commonly runs.

The engine at the time these cards were taken was under a constant load, which was kept the same as during the test. From the various sets of cards taken it seems that the indicated power of the engine should be increased by about 4.5 per cent. to get the correct value.

TEST OF THE LINCOLN WHARF POWER STATION OF THE BOSTON ELEVATED RAILWAY COMPANY.

Date of test, Thursday, May 7, 1903, 2.15 P.M., to Saturday, May 9, 1903, 6.15 P.M. Duration of test, forty hours.

Engine Room Data.

Main Engine:

Type of engine, Westinghouse-Corliss, vertical cross compound.

Diameter of high pressure cylinder	44 inches
Diameter of high pressure piston rod	9 inches
Diameter of low pressure cylinder	87 inches
Diameter of low pressure piston rod	10 inches
Stroke	60 inches
Ratio of the volumes of the high and of the low pressure cylinders	1 to 3.91
Ratio of the crank to the connecting rod	1 to 5½
Revolutions per minute	74-37

Pressures and Temperatures:

Pressure of steam at throttle (gauge)	158.1 pounds
Temperature of steam at throttle	439.3° F.
Temperature corresponding to throttle pressure absolute	369.6° F.
Degrees of superheat	69.7° F.
Pressure in receiver (gauge)	16.9 pounds
Temperature of steam in the receiver	301.5° F.
Vacuum in condenser (gauge)	11.8 pounds
Barometer	14.7 pounds

Events of Stroke. Per Cent. of Piston Displacement:

	High.			Low.	
	Head end.	Crank end.		Head end.	Crank end.
Cut-off	25.6	25.5	Cut-off	38.2	32.8
Release	98.2	97.0	Release	95.3	95.6
Compression	8.4	13.5	Compression	. .	. .

Pressures from Indicator Cards (Absolute, Pounds per Square Inch):

High Pressure Cylinder.			Low Pressure Cylinder.		
	Head end.	Crank end.		Head end.	Crank end.
Initial	165.4	168.5	Initial	31.3	30.6
Cut-off	136.6	135.6	Cut-off	23.2	24.1
Release	40.1	44.7	Release	9.4	9.8
Compression	39.2	41.7	Compression	5.4	4.9
M. E. P.	55.34	57.66	M. E. P.	14.14	13.49

Air Pump:

Type, Blake Vertical Compound, with link cross connection between piston rods . . . . . 16″ and 28″ by 21″ stroke

Revolutions of pump per minute 23.75

Flow of Steam for Air Pump:

Diameter of orifice used . . . . . .636 inches

Pressure on supply side of orifice (gauge) . . . . . 149.7 pounds

Temperature of steam on supply side of orifice . . . . . 371.5° F.

Pressure on delivery side of orifice (gauge) . . . . . 90.0 pounds

Temperature of steam on delivery side of orifice . . . . . 349.7° F.

Condensing Water and Condensed Steam passing over Weir:

Hook gauge (depth of water passing over weir) . . . . . 8.78 inches

Width of weir . . . . . 2 feet

Distance from crest of weir to bottom of weir box . . . . . 1 foot

Temperature of water entering condenser . . . . . 50.5° F.

Temperature of water and condensed steam passing over weir . . 93° F.

Formula for calculating cubic feet per second of water passing over weir:

$$Q = 3.36\, b \left[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}} \right].$$

H = hook gauge head in feet.

h = head due to velocity of approach.

b = length of crest in feet.

Drip Steam:

Total drip from separator (forty hours) . . . . . 1,650 pounds

Total drip from throttle, valve chest, etc. (forty hours) . . . 1,610 pounds

Total drip from receiver (forty hours) . . . . . 920 pounds

Boiler Room Data.

Coal:

Total coal weighed in hoppers (forty hours) . . . . . 315,370 pounds

Total coal dust weighed back and returned to the coal pocket . . 56,948 pounds

Total coal burned (forty hours) charged to the boilers . . . 258,422 pounds

Total ash (forty hours) . . . . . 50,776 pounds

Totals for Each Boiler:

(*a*) Total coal weighed in hoppers (forty hours), pounds.

(*b*) Total coal dust weighed back and returned to coal pocket (forty hours), pounds.

(*c*) Total ash (forty hours), pounds.

	Boiler No. 17.	Boiler No. 19.	Boiler No. 18.	Boiler No. 20.
(*a*)	94,460	82,856	67,888	70,166
(*b*)	24,577	19,350	6,436	6,585
(*c*)	14,177	12,421	11,743	12,435

Chemical Analysis of Coal:

	Boiler No. 17.	Boiler No. 19.	Boiler No. 18.	Boiler No. 20.	Average of four.
Volatile matter, per cent.	20.63	19.38	21.88	19.02	20.23
Fixed carbon, per cent.	65.39	70.11	66.55	70.66	68.13
Ash, per cent.	11.71	9.00	9.62	8.72	9.76
Moisture, per cent.	2.27	1.52	1.85	1.61	1.81

Heat of combustion by Mahler bomb . . . . . 14,420 B. T. U.

Chemical Analysis of Ash — Average of Three Determinations:

Volatile matter, per cent.	14.67
Fixed carbon, per cent.	65.68
Ash, per cent.	19.65
Moisture, per cent.	0.00

Water and Steam:

Total feed water (forty hours)	1,889,325 pounds
Total steam supplied to main engine (forty hours)	1,886,065 pounds

Temperatures of the Feed Water:

Entering the primary heater	54.7° F.
Leaving the primary heater	135.5° F.
At tank on boiler room floor	133.2° F.
Entering economizer of boilers No. 17 and No. 19	133.5° F.
Leaving economizer of boilers No. 17 and No. 19	205.5° F.
Entering economizer of boilers No. 18 and No. 20	135.1° F.
Leaving economizer of boilers No. 18 and No. 20	217.9° F.

Temperature of Steam at Boilers:

No. 17 = 436.3° F. No. 19 = 471.4° F. No. 18 = 443.7° F. No. 20 = 367.7° F.

Boiler pressure at header (gauge)	161.6 pounds
Temperature of steam at header	450.9° F.
Degrees of superheat in steam at header	79.6° F.

Temperature and Draft of Flue Gases in Uptake:

	Boiler No. 17.	Boiler No. 19.	Boiler No. 18.	Boiler No. 20.
Temperature	400.8° F.	413.8° F.	456.8° F.	492.6° F.
Draft (inches of water)	.57	.59	.55	.55

Temperature of flue gas in main flue near stack . . . . . 282.0° F.

Temperature of flue gas in flue . . . { Boilers No. 17 and No. 19 = 289.4° F. / Boilers No. 18 and No. 20 = 291.4° F.

Flow of Steam (Stoker Engines):

	Boilers No. 17 and No. 19.	Boilers No. 18 and No. 20.
Diameter of orifice used (inches)	.204	.205
Pressure on supply side of orifice (gauge)	146.1 pounds	153.0 pounds
Pressure on delivery side of orifice (gauge)	130.0 pounds	138.2 pounds

Surfaces:

Total heating surface, four boilers (square feet)	21,200
Total grate surface, four boilers (square feet)	360

RESULTS OF ENGINE TEST.

ENGINE, HORSE POWER, FROM CARDS AS TAKEN.	
High pressure cylinder Head end, 948.2; crank end, 946.6. Total	1,894.8 H. P.
Low pressure cylinder Head end, 947.2; crank end, 891.7. Total	1,838.9 H. P.
Total horse power of engine	3,734.0 H. P.
Horse power of engine corrected for error of indicator rig (see Remarks)	3,902.0 H. P.

	FROM DATA.	CORRECTED VALUES.
Steam furnished engine per horse power per hour	12.63 lbs.	12.08
B. T. U. per horse power per minute (actual vacuum)	235.7	223.4
Condensing water and condensed steam passing through weir per hour	1,007,223 lbs.	
Condensing water per hour	960,095 lbs.	
Condensing water per corrected horse power per hour	246.2 lbs.	
Thermal efficiency of engine	18.00%	
Efficiency of Carnot engine working between same temperatures	33.24%	
Thermal efficiency of engine in per cent. of Carnot engine efficiency	54.14%	
Electrical horse power output, 2,702 kilo watts	3,622 H. P.	
Mechanical efficiency of engine	92.8%	
Dry coal per electrical horse power output per hour	1.75 lbs.	
Dry coal per kilo watt per hour	2.34 lbs.	
Steam used by air pump (forty hours)	105,470 lbs.	
Steam furnished to air pump in per cent. of engine steam	5.59%	
Air pump steam in per cent. total steam to main engine and air pump	5.295	

The results of the boiler test are given on the next page.

RESULTS OF BOILER TEST.

Total water feed to boilers (forty hours)	1,889,325 lbs.
Total coal charged to boilers (forty hours)	258,422 lbs.
Per cent. moisture in coal	1.81
Total dry coal burned (forty hours)	253,745 lbs.
Degrees of superheat in steam at header	79.6° F.
Average temperature of feed water entering economizers	134.3° F.
Average temperature of feed water leaving economizer	211.7° F.
Total B. T. U. taken up by one pound of water (boilers and economizers)	1,130.8 B. T. U.
Equivalent evaporation from and at 212° F. per pound of dry coal	8.718 lbs.
Boiler horse power developed	1,603
Efficiency of boiler plant (per cent.)	58.4
Heat recovered by economizer in per cent. of total heat taken up from coal	6.9%
Dry coal burned per square foot of grate surface per hour	17.62 lbs.
Water evaporated from and at 212° F. per square foot of heating surface per hour	2.604 lbs.
Heat recovered from engine exhaust by primary heater per pound of feed water	80.9 B. T. U
Heat recovered from primary heater per pound of coal	591.4 B. T. U.
Per cent. of saving in coal effected by primary heater	7.15%
Steam used in forty hours by stoker engines	13,172 lbs.
Stoker engine steam in per cent. of engine steam	.699%
Steam for stoker engines in per cent. total steam to main engine and stokers	.697%
Steam for air pump and stoker engines in per cent. total steam for plant	5.91% (inc. drip), 5.92%

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